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EXPERIMENTS RELATING TO HYDRAULICS OF FIRE STREAMS.

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WITH DISCUSSION.

Although the hydraulics of fire streams may seem but an unimportant special branch of the science of hydraulics, yet when we consider that in the United States alone there is property to the value of upward of one hundred million dollars destroyed by fire each year,* and that probably twenty-five million dollars per year more is expended in maintaining fire departments, investigation in detail of the scientific principles governing the customary means of delivering water for extinguishing fires appears amply justified. That the skill of the engineer may find a most worthy field of action in the prevention of loss by fire is illustrated in the unparalleled immunity from serious fire loss enjoyed by the great cotton factories of Lowell, where for many years the arrangements for supplying water for extinguishing fire have been under the direct care of the honored Past President of our Society, Mr. James B. Francis.

The experiments to be described were mostly made in the latter part of the year 1888, and it is believed that in completeness and in effort to

* See article by Edward Atkinson, on Slow Burning Construction, *Century Magazine*, February, 1889.

secure a high degree of accuracy they form the most reliable series of experiments on fire streams yet undertaken.

The subjects investigated were:

First.—Co-efficient of discharge of nozzles of various forms.

Second.—Loss of pressure by friction in fire hose with interior surface of various degrees of smoothness.

Third.—Effect of curves in line of fire hose upon loss of pressure.

Fourth.—Effect of reduction of area of waterway at couplings upon loss of pressure in hose.

Fifth.—Height and distance reached by jets of water under various pressures.

Sixth.—Influence of size of jet upon height attained under a given pressure.

Seventh.—Comparative efficiency of various kinds of nozzles.

Eighth.—Distribution of velocity in jets.

Finally, realizing the aversion of the busy, practical man to algebraic formulas and to lengthy computations, the final practical results have been embodied in tables covering the range of sizes and pressures commonly met in practice. Much care has been taken to secure accuracy in these tables, the computations and stereotype proofs having been verified by a second party.

As a sort of preliminary index to the results attained, we may say:

1st. DISCHARGE.—(*a.*) The fire-stream tables heretofore in most general use were found to underestimate discharge of nozzles of a given size under a given pressure by from 15 to 20 per cent. (Page 327.)

(*b.*) Uniformity of co-efficient of discharge for smooth nozzles of different forms, and with the ordinary difference in smoothness of finish by different workmen, found such as to enable measurements of discharge of water under high pressure—as, for example, the delivery of a pumping engine—to be made with great accuracy by means of nozzles; the degree of accuracy thus obtainable being fully as great as by weir measurement. (Pages 330 to 333.)

(*c.*) The very accurate measurement just referred to requires the pressure to be measured at point near base of nozzle or play-pipe, so called, by means of carefully made piezometers, and requires careful calipering of the orifice of discharge. The values for discharge given in tables on pages 422 to 433, may in some cases serve for these accurate measurements, but since the exact size of orifice is likely to differ by a few

thousandths of an inch from those given in tables, or since it may be expedient to attach piezometer upon a waterway of other than $2\frac{1}{2}$ inch diameter, special computation will generally be necessary.

For quick approximate measurements of discharge, the tables given on pages 444 to 447 have been computed from the results of the experiments.

2d. FRICTION LOSS IN HOSE.—(*a.*) The actual diameter of each piece of hose was measured. It was found that hose of various makes, all nominally $2\frac{1}{2}$ inch, varied from $2\frac{7}{16}$ to $2\frac{3}{4}$ inches in internal diameter. This alone would make about 50 per cent. difference in loss of pressure by friction, and indicates that previous data, based solely on nominal diameter, is not reliable for determining comparative loss in different kinds of hose. (Page 352.)

(*b.*) The character of the internal surface of fire hose was found to affect the loss of pressure by friction to a much greater degree than generally supposed. (Page 347.)

(*c.*) As a result of these experiments, certain leading makers of ordinary rubber lined cotton fire-hose have been induced to slightly modify process of manufacture, and without materially adding to the cost have increased smoothness of interior so as to decrease the friction loss, in certain grades of hose which are much used, by 40 per cent. (Page 347.)

(*d.*) The degree of roughness of interior surface of waterway was determined and recorded by means of plaster casts and photographs with an exactness such as to give information of quantitative value as to co-efficient of roughness in the Kutter or other formulas. (Figure 47.)

(*e.*) Certain of these hose experiments are of interest as data for the study of the flow of water in pipes under very high velocities, and indicate that while loss varies nearly in simple ratio to the square of the mean velocity, yet there is a well defined divergence from this law. (Page 356.)

3d. AN INCREASE IN SIZE OF FIRE HOSE RECOMMENDED.—(Page 366.) Curves of any radius possible without cramping the hose were found to retard flow but little. The natural ordinary sinuosity of a line of ordinary fire hose was found to increase friction only about 5 per cent., and some rather curious results were obtained, indicating that within certain limits the loss due to a given amount of curvature was greater for a large radius than for a small. (Page 361.)

4th. The loss of pressure for sudden reduction and enlargement of area of water-way (as by use of couplings of small diameter) found

to agree fairly well with the theory that it equals the head corresponding to the difference in velocity due to passing from contracted channel to the larger section. (Page 368.)

5th. JETS. — (*a.*) Previous experiments on jets were very few, and records of these previous experiments gave only the height or distance attained by the extreme scattering drops; a fact of almost no value to the practical fire engineer. In these experiments much care was taken to also note the extreme limit at which the jet would serve as a practical fire stream. (Page 373.)

6th. JETS.—(*a.*) The Box formula for height of jets found approximately correct for fire streams of ordinary size, but found not to express accurately the variation in height due differences in diameter of jet. Diagrams for practical use in computing height to which jets will rise under a given pressure are presented. (Figures 56 and 57.)

7th. Jets from about forty different nozzles were compared in the endeavor to find the form giving the most perfect jet. (Page 393.)

(*a.*) Smooth nozzle was found to give a jet a little superior to that from a ring nozzle, by comparison so arranged as to give thoroughly reliable results. (Page 406.)

(*b.*) "Uniform acceleration nozzle" was found to give no better jet than conical nozzle. (Page 401.)

(*c.*) A smooth conical nozzle was found to give the best results of any tried. (Page 394.)

8th. Distribution of velocity found to be uniform throughout cross-section of jet from the best nozzles, except in immediate vicinity of walls of orifice. (Page 411.)

9th. Actual velocity of discharge in central portion of jet from both sharp-edged and conical orifices was found to equal the full theoretical velocity, and that co-efficient of mean velocity of discharge is less than unity is found to be due to retardation close to walls of orifice. (See page 414.)

In making tests of the delivery of various pumps, the writer had noted a serious discrepancy between the plunger displacement and the discharge as given by the ordinary Ellis tables for fire streams, and in the case of some three or four large pumps, which were new and apparently in excellent condition (one being an excellent two-million-gallon water-works engine), this difference appeared greater than could with reason be charged to "loss of action" in the pump. Being thus

led to examine the Ellis tables more closely and to compare different authorities, such disagreement was found that recourse to accurate experiment seemed necessary, if we were to have a reliable basis for estimates regarding fire streams.

The writer's interest in the matter thus grew out of a desire for better information upon points connected with his duties as hydraulic engineer to an association of insurance companies.

The expense of the experiments was borne mostly by certain insurance companies, known collectively as the Associated Factory Mutual Insurance Companies of New England (and Pennsylvania). These companies are, in point of fact, associations of leading manufacturers for mutual protection against fire, and the business of these companies is conducted on the theory that their organization is as much for the purpose of preventing or reducing loss by fire, as it is for the purpose of adjusting or distributing the loss when a fire does occur.

The experiments were made at Lawrence, Mass., on the premises of the Washington Mills Company, who very kindly placed at our disposal their excellent new fire pump and hydrant system, comprising fire pumps of a total nominal capacity of three thousand gallons per minute and 16-inch pipes. This hydrant system was also connected with the city water-works by a pipe 16 inches in diameter, fed in turn through a main distribution system, whose pipes are of unusually ample size, and supplied by gravity from a forty-million-gallon reservoir. The Lawrence City Water Board generously co-operated in the experiments by permitting the free use of this supply.

This gravity supply gave at the site of the experiments a hydrant pressure of about 73 pounds per square inch, and in nearly all of the experiments, or in all cases where this pressure was high enough to serve the purpose, this "City Reservoir water" was used because of the superior steadiness of the pressure.

In cases where a higher pressure was required the water was supplied by one of the mill fire pumps; in some experiments a Fales & Jenks' No. 4 rotary fire pump, and in others a No. 1 Holyoke rotary pump being used. These pumps drew Merrimack River water from the main canal, and the "City Reservoir water" was also taken from the Merrimack about 1½ miles up stream.

In these experiments where pump pressure was used, a large air chamber for removing the hammer of the pump was very simply extemporized by first drawing off the water from the fire-pipes within the

adjacent mill, and after these were thus filled with air, then again opening the gates to them from the ground mains.

During none of the experiments was the water turbid or noticeably different from its ordinary normal condition. Analyses made by the chemist of the Massachusetts State Board of Health at various times during the experiments showed water drawn from the same source to contain a residue on evaporation of about four parts per one hundred thousand. The specific gravity of a natural water may be affected by dissolved gases in such a way as to in part neutralize the effect of the solid matter contained, and it is probable that this water differed in weight from distilled water no more than would correspond to $\frac{2}{100}$ pounds per square inch in a column 1 000 feet high.

The units of pounds per square inch for pressures, and of United States gallons of 231 cubic inches per minute for discharges, were adopted, by reason of these being the units most commonly used by fire engineers, pump builders and water-works superintendents, although the writer recognizes that in general it is desirable for the hydraulic engineer to state water pressures in feet head, and discharges in cubic feet per second.

In computing velocities the excellent tables in Francis' "Lowell Hydraulic Experiments" were used.

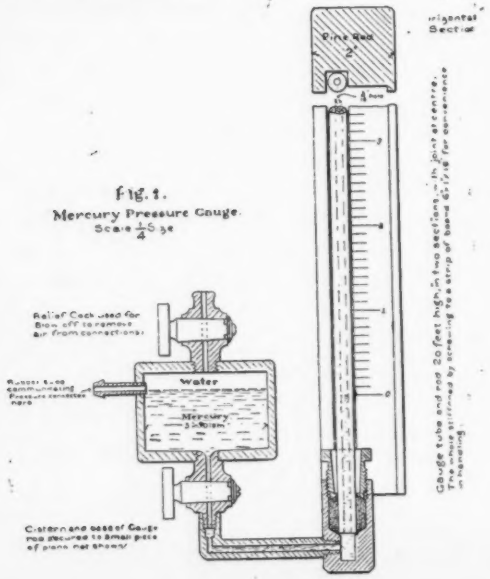


Fig. 1.
Mercury Pressure Gauge.
Scale $\frac{1}{4}$ Size

Measurements of Water Pressure.

The writer believes, as the result of considerable experience, that the ordinary Bourdon gauge is not by itself a sufficiently accurate and unvarying instrument for first-class scientific work such as requires accuracy within 1 or 2 per cent., by reason of the frequent derangements and change of scale to which even the best Bourdon test gauges are liable. Therefore the standard gauge adopted for measurement of pressures in these experiments was an open mercury column. Two semi-portable gauges of this kind (see Fig. 1) were constructed especially for these experiments, and these mercury gauges were used almost exclusively in all the following experiments on friction loss in hose, discharge of nozzles, comparative efficiency of nozzles, and height of jets.

Two excellent Crosby test gauges and one Ashcroft standard test gauge were at hand, but were used only in some of the minor determinations, and were frequently verified by comparison with the mercury columns and corrected accordingly.

These mercury columns were each 20 feet in height, reading to about 117 pounds per square inch pressure. Their scales were graduated to read directly in pounds per square inch, and to include the correction for lowering of surface of mercury in cistern.

The mercury was procured from Mr. Huddleston, the well known barometer maker, who stated it to be pure. The value 13.563 for specific gravity of mercury at 60 degrees Fahr. was adopted. (Authority, Regnault, P. A., 62–50. See Clark's Constants of Nature.) The weight of a cubic inch of water at 0 degrees C. was taken as 0.03610 pounds, on authority of J. B. Francis, "Lowell Hydraulic Experiments," page 29; and, therefore, by comparison we derive weight of 1 cubic inch of mercury at 60 degrees Fahr. = 0.4896 pounds. Height of mercury column corresponding to 1 pound per square inch = 2.0425 inches. The diameter of glass tube was about $\frac{3}{16}$ inches or about the same as for an ordinary barometer and diameter of cistern 3 inches.

Therefore, to compensate for lowering of mercury surface in cistern, scale of this instrument was graduated with 1 pound per square inch = 2.0343 inches.

Error due to capillarity in the $\frac{3}{16}$ inch tube was avoided by setting scale to read zero when pressure was zero, amount of mercury in cistern having been previously adjusted so that its surface was just at level of entrance into cistern of tube transmitting the pressure. Since there was occasionally a slight loss of mercury while forcing water through tubes and cistern, for making sure of absence of air bubbles in tubes, note was made before and after each set of experiments of reading of mercury column with pressure removed, and mercury was added to bring column up to the zero level if necessary, or a slight correction made to the observed reading.

For the benefit of future experimenters in hydraulics, I would say that these semi-portable mercury columns proved very satisfactory in

their operation. Very little of the difficulty of leaky joints noted by M. Darcy was met with, mainly because we profited by his experience, used a less cumbrous form of apparatus, and avoided joints wherever possible, making glass tube in only two pieces, and joining these by heavy rubber tube containing cloth insertion, tightly wired on. Joints in iron fittings need to be very much closer to hold mercury than to hold water, and as the ordinary taper-screw pipe-joint will be found to give trouble, nothing but an accurate "shoulder fit" should be used. Cisterns were made of wrought-iron with welded joints, and interior of cistern and iron connections was japanned after putting together, to increase tightness and prevent rust.

As stated above, the graduation assumed the diameter of the glass tubes to be $\frac{3}{16}$ inch. These tubes were afterwards accurately calibrated by noting weight of mercury required to fill them to certain heights, and corresponding corrections deduced. For gauge A maximum correction at 100 pounds $= -0.08$ pounds, and for gauge $B + .01$ pounds. This result was exactly confirmed by placing the two gauges side by side, and subjecting both to identical pressures through nearly their whole range.

In a gauge of this construction the lowering of the surface of mercury in cistern lowers the datum of the gauge; but the variation due to this cause for 50 pounds pressure, for instance, would be only 0.02 pounds per square inch, and thus almost inappreciable. Variation of 20 degrees Fahr. in temperature of mercury, from 60 to 80 degrees, would affect indication of gauge only about $\frac{1}{1000}$ part, while it would affect a water column $\frac{2}{1000}$.

All things considered, it would seem reasonable to expect these mercury gauges, including corrections applied, to measure a pressure correctly within one-tenth of 1 per cent.

The datum plane to which all heads and pressures were referred was a level plane passing through center of orifice of discharge of nozzle. It was in the first place established and marked at convenient points near by all gauges and nozzle rest by means of a very accurate engineer's level.

The intention was to set center of nozzle orifice and the zero point of all gauges exactly at this level; but as it was rather difficult to do this with great exactness, the gauges and the nozzles were set to coincide with the datum marks approximately, and then, as a further check intended to lessen errors possible from capillarity, air bubbles, defective graduation or error of measurement, etc., their relative heights were very carefully verified by water leveling, immediately after each series of experiments, before disturbing apparatus. That is, the gauges were compared at various pressures by closing end of hose at nozzle, so there should be no current, and so that the hose thus served meanwhile merely as a free channel of communication between the gauges, which, if correct and set exactly level, should under these circumstances read alike.

The elevation of orifice of nozzle, relatively to zero of gauge connected therewith, was similarly verified by water levels, by connecting an open glass tube about 1 inch diameter (or large enough to avoid sensible error by capillarity) to nozzle by a rubber tube 1 inch in diameter by 1 foot long. Then, after filling the hose from the hydrant, and carefully closing hydrant gate so water would just rise to some certain mark on the glass tube—say, for instance, 1.000 foot above level of center of orifice—the pressure gauge was read at same time. By using several repetitions these comparisons furnished very accurate means for determining, under the exact conditions of the experiments, the slight errors of adjustment of gauges. Corrections as thus determined have been applied in all cases. Great care was taken to avoid errors due to air bubbles in connections.

Although a difference of pressure of .01 pound was revealed by the gauges, and the observations were recorded to hundredths of a pound, yet, owing to possible errors in the gauge itself, such as those mentioned on page 8, and slight errors in determining the level of the gauge relative to datum plane, I consider that any set of readings may, perhaps, be in error by not more than 0.15 pound, except that in some cases, when supply came from the pumps, this limit of error may have been slightly increased by uncertainty due to fluctuations of pressure.

Piezometers.

For measuring the water pressure within the hose at any required point, and for measuring the pressure existing at base of play-pipe, use was made of piezometer couplings of the form shown in Fig. 2.

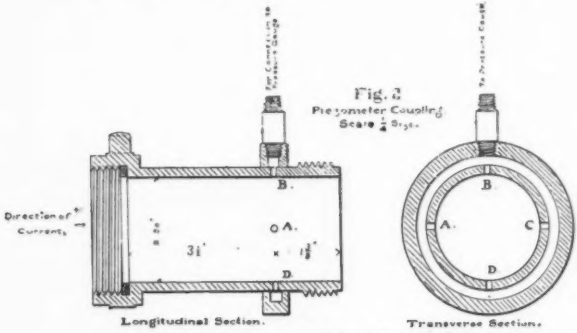


Fig. 2
Piezometer Coupling
Scale ¼ Size.

A. B. C. D. = Piezometer Orifices. Both screw ends fit Standard hose couplings so this may be introduced at any joint in a line of hose or at base of play pipe, coupling thus forming part of the line

The one shown was of an internal diameter of 2.50 inches, and was used in all experiments on 2½-inch hose and nozzles adapted for the same. Three piezometer couplings of this size were provided. Others of 2¼ and 2 inch diameter were provided for use in experiments on hose of these sizes.

This piezometer coupling consisted mainly of a brass tube about 5½ inches long, which when in place formed part of the line of hose. The interior was bored out and finished with much care, and great care was taken that the piezometric orifices in the walls of the tube should be normal to the surface and without any burr at edge.

There were four of these ⅛-inch piezometric orifices, all in the same plane of cross-section, 90 degrees apart, and about 4 inches down from the up-stream end of the tube. All communicated with each other by an exterior channel or chamber encircling the tube, and the pressure gauge was connected to this chamber. This arrangement was devised with the object that if direction of current, by reason of bends or disturbances up stream, happened to impinge a little harder on one side of the conduit than the other, the piezometric reading should not thereby be rendered erroneous, but should indicate the mean pressure existing on the walls in that cross-section. We may remark that neglect of some such precaution may lead to very noticeable error. It may be well to add in this connection that certain anomalous results in various experiments upon flow of water in pipes which have made some observers question the general accuracy of piezometric indications may doubtless be due to surface not being exactly parallel to current or to a projection of the piezometric orifice within the main conduit. Thus, for instance, in the case of hose, if, with a good fire stream flowing, it was attempted to measure pressure through a piece of ⅛-inch gas pipe screwed into a hole drilled in a coupling and projecting ¼ inch inside, the indicated pressure might be from 1 to 2 pounds per square inch in error.*

Measurement of Quantity Discharged.

The number of gallons per minute discharged in all experiments on friction in hose and upon delivery of nozzles was measured in a tight and rigid rectangular tank holding about 1 350 gallons, built of heavy

* In this connection see the very complete experiments upon piezometers by Hiram F. Mills, Proceedings American Academy Arts and Science, 1878.

plank and smoothly lined with sheet zinc, with joints soldered perfectly tight. Its area was determined by the average of lengths and widths measured at about twenty different points, and the height of water in it, immediately before and after experiment, was determined by the glass tube of about 1 inch inside diameter (by this large diameter avoiding errors due to capillary attraction), to which was attached a scale very accurately graduated to hundredths of a foot, and read by estimation to $\frac{1}{1000}$ foot.

With the possible sources of error in view, I think that in general the error in any single measurement of quantity did not exceed one-third of 1 per cent. This tank is shown in Fig. 3.

The discharging nozzle was only $3\frac{1}{2}$ feet distant from this tank. It pointed upward at an angle of 30 degrees, thus simulating natural conditions; and in the intervals between the experiments nozzle was deflected slightly to one side and the jet wasted and fell into the river south of the tank. When all was ready for the experiment, by deflecting the nozzle and hose pipe back into line, the water from it was caught in a hood which deflected it all downward into the tank. Thus to get the number of gallons discharge per minute the water was first allowed to get into a settled condition of steady flow in the hose, then by a slight motion of the hose pipe the jet was deflected into the tank, and when the tank was nearly filled was deflected out again, the time of fill being taken by a stop watch read to tenths of seconds. The error in measurement of time of filling could not, I think, often exceed one-fifth of 1 per cent., and generally was less.

Thus I think that in general we may rely upon a single measurement of the number of gallons per minute discharged by the nozzle as correct within one-half of 1 per cent., and that the average results of a series would be much closer.

Co-efficient of Discharge of Nozzles.

In many experiments the friction loss in a given sample of hose due to a certain rate of flow, and also the co-efficient of discharge of a given nozzle attached to this hose due to a certain pressure, were determined simultaneously. In such cases the mercury gauge, Fig. 3, served to indicate the pressure on the play-pipe actuating the discharge, and at the same time served also to show the pressure at the down-stream end of the line of hose.

In other experiments the sole attention was given to determining the pressure existing at base of a given play-pipe and the corresponding number of gallons per minute discharged; but in all experiments on discharge the nozzle and play-pipe were connected to a line of hose, and, as nearly as possible, under the practical conditions of use. It will be noted from Fig. 3 that for a distance of 3 feet up stream from play-pipe piezometer, hose was laid straight.

One observer observed and recorded the reading of mercury pressure gauge each half minute. Thus the value obtained for each experiment was the mean of from six to twelve independent observations and the error from slight variations of hydrant pressure was reduced to a minimum. Such fluctuations were small. When water from city reservoir was used, as was the case in all experiments except those with very high pressures, the general range of fluctuation in the course of an experiment did not exceed $\frac{1}{2}$ or $\frac{3}{4}$ pound, and between successive observations did not exceed from 0.1 to 0.2 pound. In those experiments under high pressures, when supply was furnished by a large rotary fire pump, the fluctuation between successive observations of pressure gauge at nozzle was often one-half pound.

Taking all the known possible sources of error into consideration, I think we may feel confident that the head acting on centre of orifice of discharge is determined within 0.20 pound for pressures from reservoir, and within 0.50 pound for pressure from pump, and that the averages of series of experiments are closer. An examination of the plotted results or of tables 1 to 4 shows the agreement of the different experiments to be well inside the limits of error just stated.

The orifices were all calipered by the writer with much care with fine micrometer calipers, and except in one or two instances where the orifice was apparently not quite cylindrical it is believed that the recorded figure is correct within $\frac{1}{1000}$ inch. In the undercut ring nozzles it was difficult to determine the diameter at the exact point governing the size of stream, by reason of the appreciable dullness of the edge; but these are believed to be not more than $\frac{5}{1000}$ inch in error, and the square ring nozzles not more than $\frac{3}{1000}$.

To sum the whole matter up, we may have confidence that in general our determinations of the co-efficient of discharge of nozzles were certainly correct within one-half of 1 per cent., and that probably the mean of the values found for a given nozzle was correct within a somewhat smaller limit.

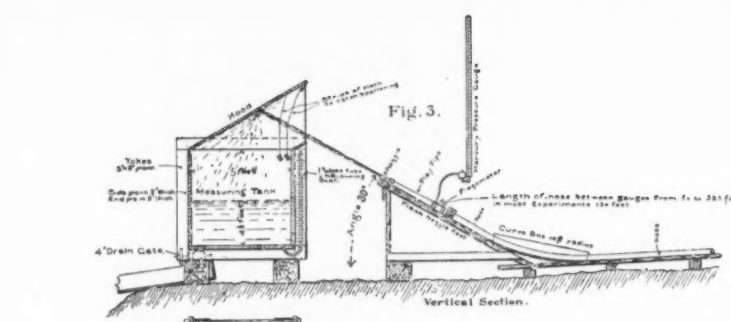


Fig. 3.

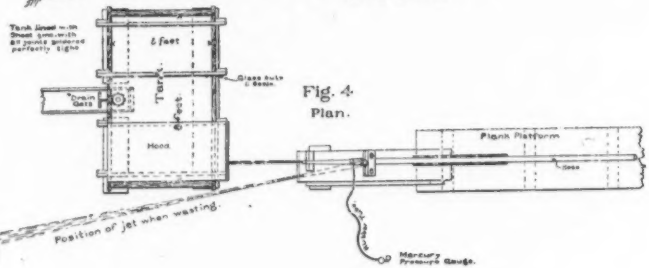


Fig. 4
Plan.

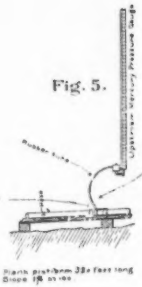


Fig. 5.

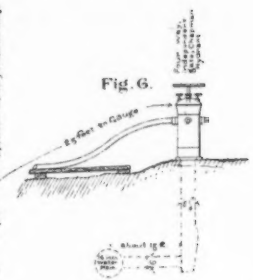


Fig. 6.

The temperatures of water as given in the table are probably correct within one or two degrees; but temperature of air was observed with less care, and as at times one part of the apparatus was in the sun while another was in the shade, this is perhaps uncertain to the extent of 5 degrees.

The following tables, taken in connection with the drawings, explain themselves.

Table No. 1 embraces the ordinary range of sizes found in the market, and these nozzles were of the type of which it is believed more are now actually used than any other single style. All the subsequent experiments on jets indicated that this style (with corner at end of cone slightly rounded as in Fig. 16) equaled in efficiency any form of nozzle tried. In all the nozzles of Table No. 1 the corner at end of cone was left full and sharp, except so far as slightly rounded by the final finishing with emery cloth.

By reference to the drawings it will be noted that there was with each nozzle a slight enlargement of waterway at end of play-pipe within butt of nozzle; it being the practice of manufacturers to give a slight excess of size here, so as to be on the safe side in avoiding the projection of a sharp corner into stream as in Fig. 22.

From nozzle D (Fig. 15), Table No. 2, it will be seen that this slight recess or enlargement exerted no appreciable influence on the discharge, and in other experiments made on distance and character of jets, as shown in Fig. 55, it was found impossible to detect any difference in appearance of stream whether the recess existed or was filled by the thin hollow cone, as in Fig. 15. On the other hand, it was found by similar experiments that if at base of nozzle there was a slight projection into the stream, as shown in Fig. 22, nozzle K, not only was discharge slightly diminished (as shown in Table No. 2), but there was a very noticeable "tearing to pieces" of the jet.

The co-efficient of discharge of a nozzle throughout these experiments has for practical convenience been considered as that due to the play-pipe and nozzle combined, a taper play-pipe being really a part of the nozzle.

The reason for the slightly larger co-efficient of the ¾ and ⅞-inch nozzles is due to the relative decrease of friction loss within the play-pipe consequent on area of waterway through play-pipe bearing a larger

TABLE No. 1.

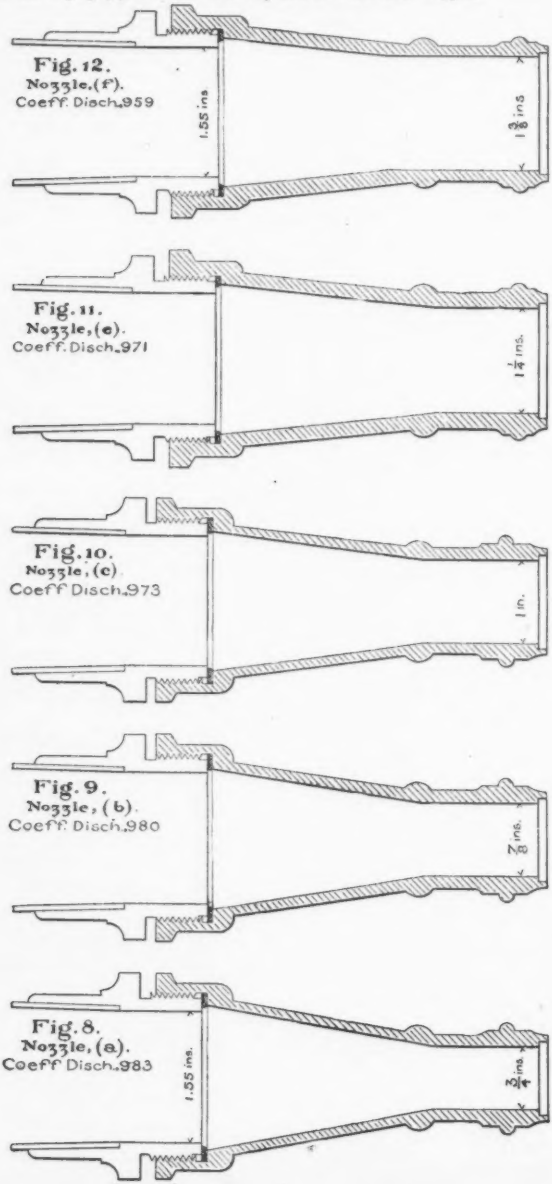
Co-efficient of Discharge of Smooth-cone Nozzles of Various Sizes.

Reference Mark of Nozzles. See Figs.	Nominal Size, inches.	Actual Diameter of Orifice, Inches.	Observed Pressure at Base of Play-pipe lbs. per sq. inch.	Actual Discharge, gallons per minute.	No. of Obs. on Curve near Point.	Corr. for Head due Vel. past Piez., lbs.	Static Pressure, pounds.	Theoretical Velocity due Pressure, feet per second.	Theoretical Discharge, gallons per minute.	Co-efficient of Discharge.	Mean Value Co-efficient.	Remarks.
(*a*)	$\frac{3}{4}$	.751	60.0	129.3	1	.46	60 46	94.83	130.9	.988	.983	Average temperature of water, 71 degrees Fahr. (range of temperature water, 69 degrees to 73 degrees); temperature of air from 60 degrees to 90 degrees. Nozzles (*A*) and (*a*) to (*g*), inclusive, were each attached to the 30-inch play pipe, shown in Fig. 13, when tested, and pressure gauge was connected to piezometer at base of play-pipe, as shown in the same figure.
			50.0	117.2	1	.38	50.38	86.56	119.5	.981		
			40.0	104.4	1	.31	40.31	77.43	106.9	.977		
			25.0	83.4	1	.20	25.20	61.23	84.5	.987		
(*b*)	$\frac{7}{8}$	.880	80.0	205.2	2	1.21	81.21	109.90	208.3	.985	.982	This play-pipe was made from brazed copper, taper tubing, and was a good ordinary play-pipe taken from regular stock of A. J. Morse & Son, fairly smooth inside, but contained the ordinary roughness incident to a brazed seam, and was not specially polished.
			60.0	177.0	3	.91	60.91	95.18	180.4	.981		
			50.0	162.0	1	.74	50.74	86.87	164.7	.984		
			30.0	125.0	1	.44	30.44	67.29	127.6	.980		
(*c*)	1	1.001	50.0	208.5	1	1.26	51.26	87.31	214.1	.974	.972	The nozzles were all of brass, and were the ordinary smooth-cone nozzle, with Amoskeag thread, and were taken at random from regular stock of A. J. Morse & Son. The smoothness of interior was only the ordinary polish of a first-class brass finisher, the tool marks merely being polished out by emery cloth. The "straight part" was bored out to size by a reamer, and corner at junction left sharp, except as rounded very slightly by the emery cloth. These nozzles are shown in Figs. 8 to 13.
			40.0	186.4	1	1.00	41.00	78.09	191.6	.973		
			30.0	161.0	1	.74	30.74	67.62	165.9	.970		
(*A*)	$1\frac{1}{8}$	1.126	50.0	266.5	5	2.04	52.04	87.97	273.0	.976	.976	
			40.0	238.2	4	1.64	41.64	78.70	244.3	.975		
			30.0	205.9	4	1.22	31.22	68.15	211.5	.973		
			20.0	169.0	2	.82	20.82	55.65	172.7	.979		
(*e*)	$1\frac{1}{4}$	1.250	54.0	344.2	2	3.40	57.40	92.40	353.4	.974	.971	These experiments were made at various times between August 22d and October 15th. A large number of observations on these nozzles (*a*) to (*g*) were obtained incidentally to the experiments on friction loss in the various samples of hose given in Table No. 5. These were plotted on cross-section paper, on scale 1 pound = 1 cm., and 1 gallon per m. = 2 mm., and the values in the fourth and fifth columns are taken from the curve drawn through the plotted observations.
			50.0	330.2	1	3.18	53.18	88.93	340.2	.971		
			40.0	295.5	2	2.50	42.50	79.51	304.1	.972		
			30.0	256.0	5	1.86	31.86	68.84	263.3	.972		
			25.0	233.4	4	1.56	26.56	62.84	240.4	.971		
			15.0	180.4	4	.94	15.94	48.69	186.2	.968		
(*f*)	$1\frac{3}{8}$	1.375	30.0	310.6	6	2.80	32.80	69.84	323.2	.961	.959*	In Tables Nos. 2, 3 and 4 the quantities given are in each case the result of only a single experiment.
			25.0	283.0	4	2.28	27.28	63.70	294.8	.960		
			20.0	252.0	2	1.82	21.82	56.96	263.6	.956		
(*g*)	play-pipe with noz. off	1.550	20.0	338.5	1	3.31	23.31	58.87	346.2	.978	.976	* In experiments on (*f*) the throat of play-pipe was really too small for a nozzle of this size, hence low co-efficient.
			12.0	261.0	2	1.95	13.95	45.55	267.9	.974		

Ordinary Smooth Cone Nozzles.

Scale ¼ actual size

Each of these was tested on play-pipe shown in Fig. 13 and Coeff. includes effect of friction loss in play-pipe which is relatively less for the smaller nozzles



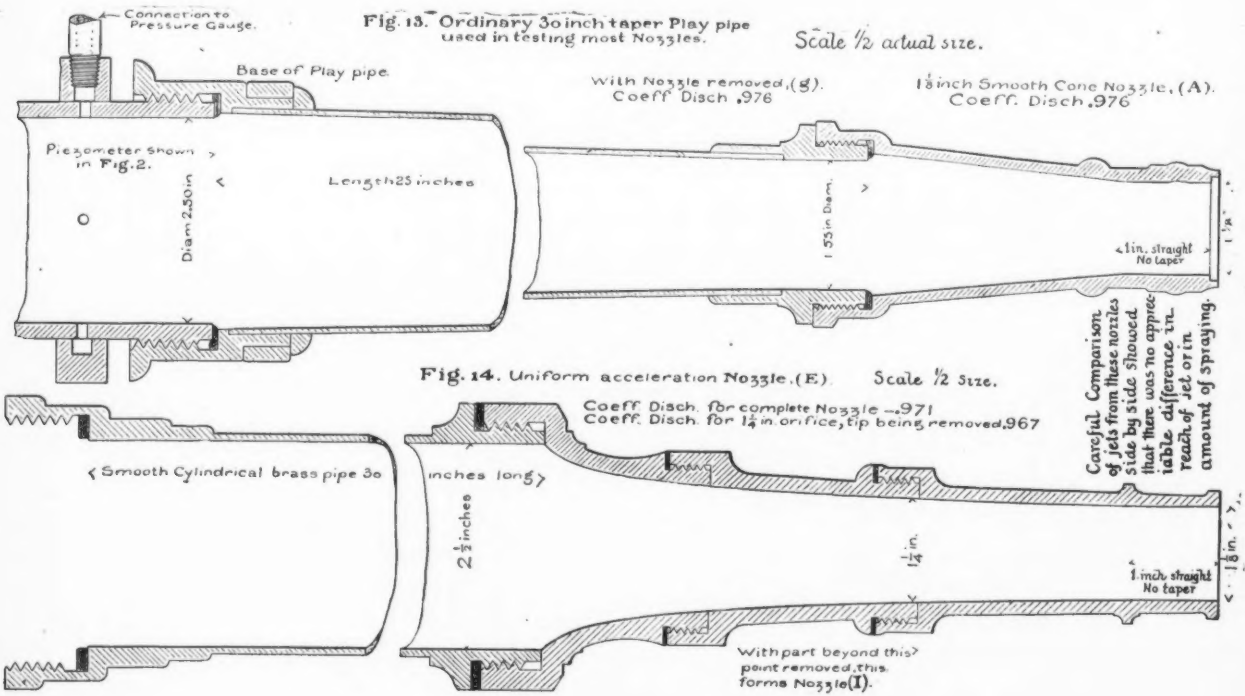

Connection to Pressure Gauge.
Base of Play pipe.
Piezometer shown in Fig. 2.
Diam 2.50 in
Length 25 inches
With Nozzle removed, (g).
Coeff. Disch. .976
1.53 in Diam.
1 in. straight No taper
1⅛ inch Smooth Cone Nozzle, (A).
Coeff. Disch. .976
1 7/8"
Careful Comparison of jets from these nozzles side by side showed that there was no appreciable difference in reach of jet or in amount of spraying
Smooth Cylindrical brass pipe 30 inches long
Coeff. Disch. for complete Nozzle = .971
Coeff. Disch. for 1¼ in. orifice, tip being removed .967
2½ inches
1¼ in.
1 inch straight No taper
1⅛ in.
With part beyond this point removed, this forms Nozzle (I).

Fig. 13. Ordinary 30 inch taper Play pipe used in testing most Nozzles. Scale ½ actual size.

Fig. 14. Uniform acceleration Nozzle. (E). Scale ½ size.

Scale ½ size.

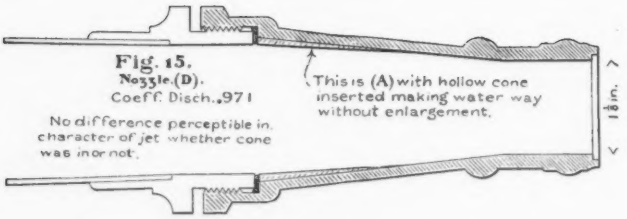


Fig. 15.
Nozzle (D).
Coeff. Disch. .971

This is (A) with hollow cone inserted making water way without enlargement.

No difference perceptible in character of jet whether cone was in or not.

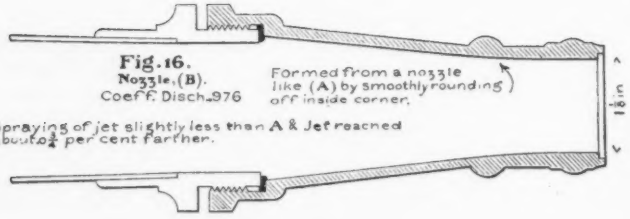


Fig. 16.
Nozzle (B).
Coeff. Disch. .976

Formed from a nozzle like (A) by smoothly rounding off inside corner.

Spraying of jet slightly less than A & Jet reached about ¾ per cent farther.

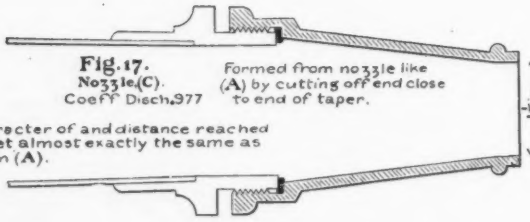


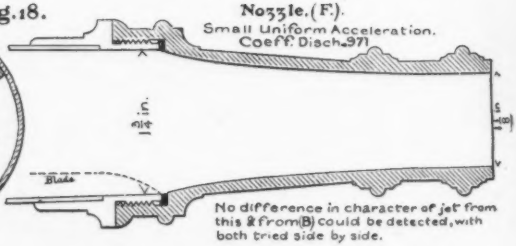
Fig. 17.
Nozzle (C).
Coeff. Disch. .977

Formed from nozzle like (A) by cutting off end close to end of taper.

Character of and distance reached by jet almost exactly the same as from (A).

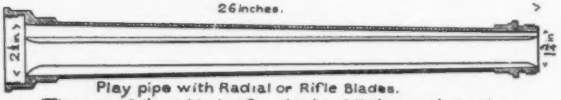
Fig. 18.

Section of Play pipe showing Radial blades for straightening Current.



Nozzle (F).
Small Uniform Acceleration.
Coeff. Disch. .971

No difference in character of jet from this & from (B) could be detected, with both tried side by side.



Play pipe with Radial or Rifle Blades.
The use of these blades found to be of little practical value

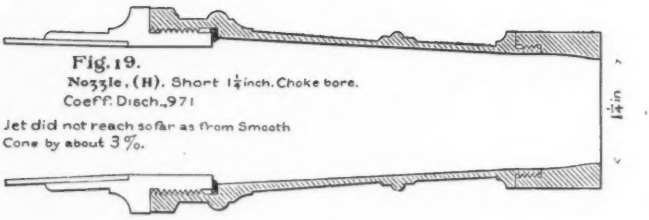


Fig. 19.
Nozzle, (H). Short 1¼ inch. Choke bore.
Coeff: Disch. .971
Jet did not reach so far as from Smooth Cone by about 3%.

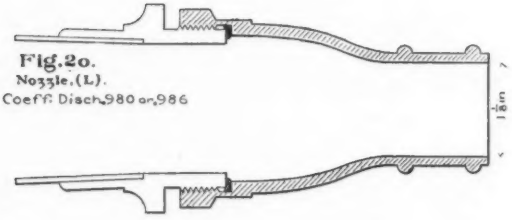


Fig. 20.
Nozzle, (L).
Coeff: Disch. .980 or .986

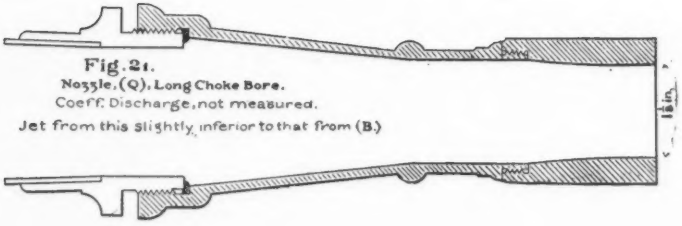


Fig. 21.
Nozzle, (Q). Long Choke Bore.
Coeff: Discharge, not measured.
Jet from this slightly inferior to that from (B.)

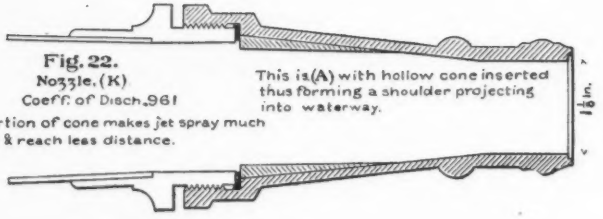
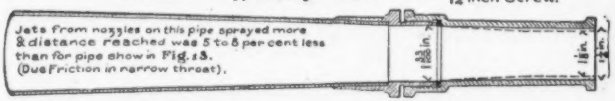


Fig. 22.
Nozzle, (K)
Coeff: of Disch. .961
This is (A) with hollow cone inserted thus forming a shoulder projecting into waterway.
Insertion of cone makes jet spray much more & reach less distance.

Fig. 23. Ordinary 36 inch Screw Nozzle Play pipe, with narrow throat. – { Full line = Nozzle (J), 1⅛ inch Diam. Coeff. Disch. .946 / Dotted line = Nozzle (P), 1⅛ inch Diam. } 1¼ inch Screw.

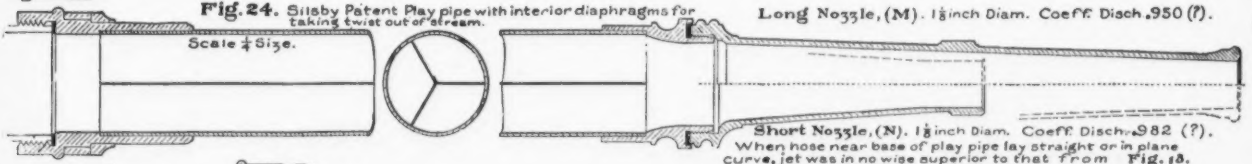
Scale ¼ Size.



Jets from nozzles on this pipe sprayed more & distance reached was 5 to 8 per cent less than for pipe shown in Fig. 18. (Due Friction in narrow throat).

Fig. 24. Silsby Patent Play pipe with interior diaphragms for taking twist out of stream.

Scale ¼ Size.



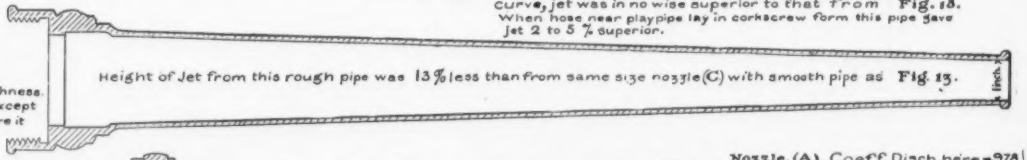
Long Nozzle, (M). 1⅛ inch Diam. Coeff. Disch. .950 (?).

Short Nozzle, (N). 1⅛ inch Diam. Coeff. Disch. .982 (?).

When hose near base of play pipe lay straight or in plane curve, jet was in no wise superior to that from Fig. 18. When hose near play pipe lay in corkscrew form this pipe gave jet 2 to 5 % superior.

Fig. 25.
Scale ¼ Size

Cast Brass Play Pipe. Inside retained all the roughness of a dry sand casting, – except for 1½ inches next tip, where it was reamed out smooth.

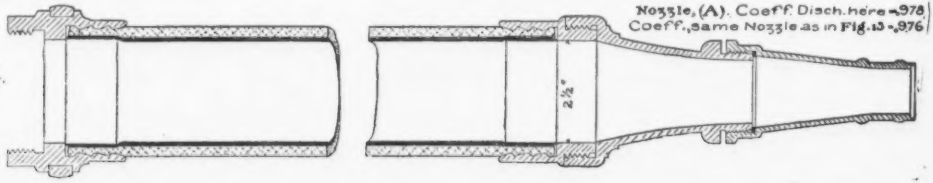


Height of Jet from this rough pipe was 13 % less than from same size nozzle (C) with smooth pipe as Fig. 13.

Fig. 26.

Flexible Playpipe 2½ in. Diam. of Cotton Fabric lined with rubber.

No perceptible difference in spraying between this & Fig. 13. Apparently height of jet from this was 1 or 2 per cent less.



Nozzle, (A). Coeff. Disch. here = .978
Coeff., same Nozzle as in Fig. 13 = .976

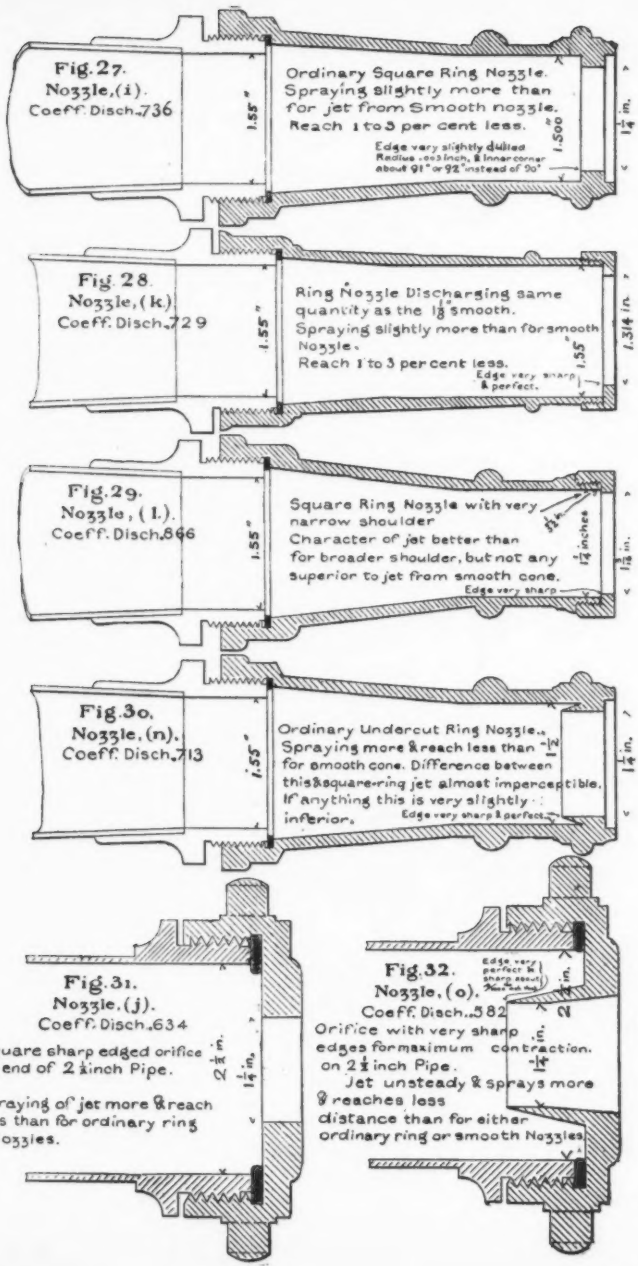


Fig. 27.
Nozzle, (i).
Coeff. Disch. .736
1.55"
Ordinary Square Ring Nozzle.
Spraying slightly more than for jet from Smooth nozzle.
Reach 1 to 3 per cent less.
Edge very slightly dulled
Radius .003 inch, & Inner corner about 91° or 92° instead of 90°
1.500
1¼ in.
Fig. 28.
Nozzle, (k).
Coeff. Disch. .729
1.55"
Ring Nozzle Discharging same quantity as the 1⅜ smooth.
Spraying slightly more than for smooth Nozzle.
Reach 1 to 3 per cent less.
Edge very sharp & perfect.
1.55"
1.314 in.
Fig. 29.
Nozzle, (l).
Coeff. Disch. .866
1.55"
Square Ring Nozzle with very narrow shoulder
Character of jet better than for broader shoulder, but not any superior to jet from smooth cone.
Edge very sharp
1¼ inches
1⅜ in.
Fig. 30.
Nozzle, (n).
Coeff. Disch. .713
1.55"
Ordinary Undercut Ring Nozzle.
Spraying more & reach less than for smooth cone. Difference between this & square-ring jet almost imperceptible. If anything this is very slightly inferior.
Edge very sharp & perfect.
1½
1¼ in.
Fig. 31.
Nozzle, (j).
Coeff. Disch. .634
Square sharp edged orifice on end of 2½ inch Pipe.
Spraying of jet more & reach less than for ordinary ring Nozzles.
2½ in.
1¼ in.
Fig. 32.
Nozzle, (o).
Coeff. Disch. .582
Edge very perfect & sharp about
1¼ in.
Orifice with very sharp edges for maximum contraction.
on 2½ inch Pipe.
Jet unsteady & sprays more & reaches less distance than for either ordinary ring or smooth Nozzles.

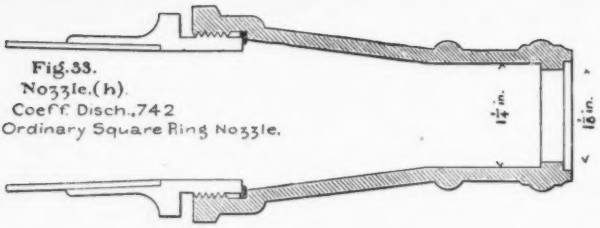


Fig. 33.
Nozzle. (h).
Coeff. Disch. .742
Ordinary Square Ring Nozzle.

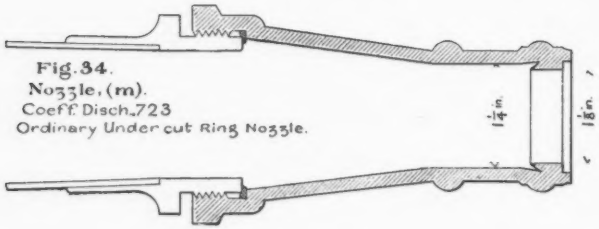


Fig. 34.
Nozzle, (m).
Coeff. Disch. .723
Ordinary Undercut Ring Nozzle.

Scale ½ size.

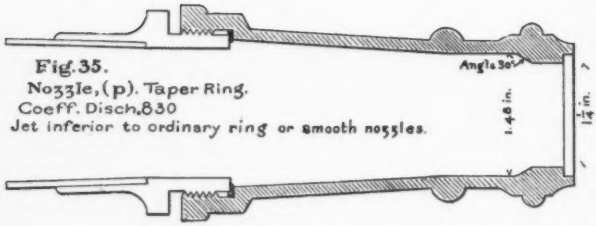


Fig. 35.
Nozzle, (p). Taper Ring.
Coeff. Disch. .830
Jet inferior to ordinary ring or smooth nozzles.

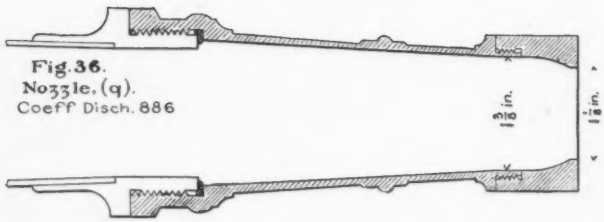


Fig. 36.
Nozzle, (q).
Coeff. Disch. .886

Nozzles for Siamese.

Scale ¼ Size.

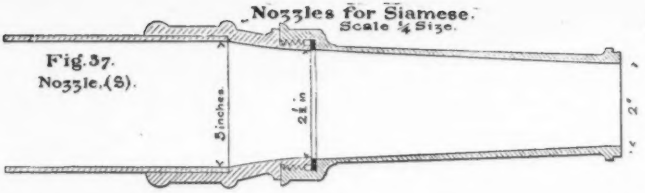


Fig. 37.
Nozzle, (s).

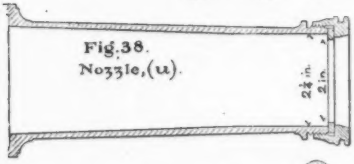


Fig. 38.
Nozzle, (u).

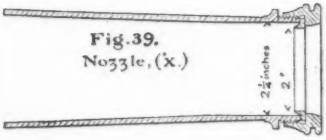


Fig. 39.
Nozzle, (x.)

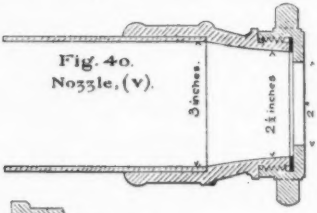


Fig. 40.
Nozzle, (v).

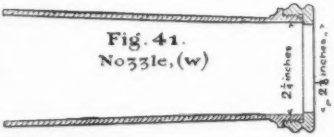


Fig. 41.
Nozzle, (w)

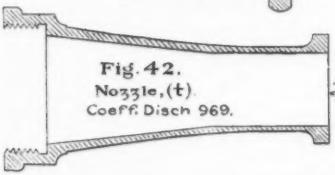


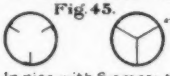
Fig. 42.
Nozzle, (t).
Coeff: Disch 969.

The smooth nozzles (s), & (t) are believed to have proved most satisfactory on the whole, but the large ring nozzles (u), (x), & (w) gave results equally good within 1% in distance reached

Transverse Section of Siamese Pipe.

Showing blades ⅛ inch thick for straightening Current. These extended whole length of Barrel

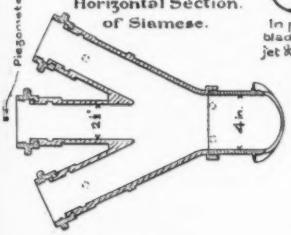
Fig. 45.

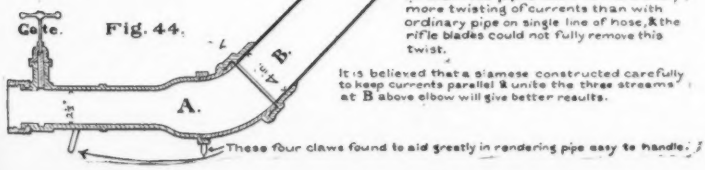


This Style gave best results

In pipe with Siamese these blades found to greatly improve jet & decrease spraying 25%

Fig. 43.
Horizontal Section of Siamese.





Another Siamese pipe was tested which was similar except that waterway from A to B & C was but 4" diam. Jet reached 7% less height.

In Siamese pipes like this there is far more twisting of currents than with ordinary pipe on single line of hose, & the rifle blades could not fully remove this twist.

It is believed that a siamese constructed carefully to keep currents parallel & unite the three streams at B above elbow will give better results.

Cocks.

Fig. 44.

These four claws found to aid greatly in rendering pipe easy to handle.

ratio to area of nozzle, and the smaller co-efficient of the $1\frac{3}{8}$-inch nozzle is due to the relatively small size of throat, or small end, of play-pipe.

Table No. 2 and the drawings on pages 318 to 322 are of interest, first, as showing that the co-efficient of discharge of nozzles is not very sensitive to peculiarities of form or finish of nozzle, but that nozzles of same general style made at different times and places may be relied upon to give for a given pressure and area of outlet discharges which are identical within the practicable limits of measurement; and the table is of interest secondly, as showing by agreement of independent observations the accuracy of the means adopted in making the experiments.

A comparison with co-efficients of discharge found by other experimenters is interesting. The most accurate set of previous experiments of which the writer has knowledge are those of Edmund B. Weston, M. Am. Soc. C. E., made at Providence in 1877, and reported in the Transactions of the American Society of Civil Engineers, November, 1884. The description there given merely says "the quantity of water discharged was measured," but gives no means of judging of the precision with which this was done. His pressures were measured only by good Bourdon gauges. His piezometer coupling was attached directly to base of play-pipe, but possessed only a single opening for communicating pressure to gauge, and indication may thus have been slightly influenced by any obliqueness of current due to bends in hose, etc. The degree of precision with which diameter was measured is not stated. As the mean of some thirty-five experiments in all, under heads ranging from about 17 to 57 pounds per square inch and averaging about 30 pounds, Mr. Weston obtained the following values for the co-efficient of discharge (see his diagram No. 5):

$\frac{7}{8}$ nozzle	.974
1 "	.963
$1\frac{1}{8}$ "	.975
Mean value	.971

These were cone nozzles somewhat similar to those shown in Figs. 7 and 13.

It is thus seen that although the conditions for accuracy were less favorable than in the experiments now presented, they agree remarkably well.

Some experiments of Hamilton Smith, Jr., M. Am. Soc. C. E., on discharge under extremely high heads, may be of interest in this connection. (See Hamilton Smith, Jr.'s "Hydraulics," New York, Wiley & Sons, 1886, pages 285 to 287, also page 207.)

His nozzles were such as are used in connection with "hurdy-gurdy" water wheels, and the part corresponding to play-pipe was a tapering pipe (length not stated) about 7 inches in diameter at butt and 4 inches at beginning of nozzle proper. Thus since co-efficient includes friction loss within this "play-pipe" pipe in both cases, Mr. Smith's co-efficient of discharge might naturally be very slightly larger than the writer's, by reason of this larger play-pipe, and the slight divergence or small increase of diameter near discharging orifice of most of his smooth nozzles would, though probably without effect, if anything, make values a very little larger.

For smooth conical nozzles of cast-iron, about 1 inch and 1¼ inch diameter, with interior surface very smoothly finished, length of nozzle being about 12 inches and converging from about 4 inches diameter at its base, and diverging very slightly at the end, he obtained an average value for co-efficient of discharge of 1.005, and for his nozzle C^1, in which the slightly divergent part next orifice was cut off, the convergence of interior of about 8½ degrees thus continuing to the very end, he found co-efficient to be 1.006, under a head of about 145 pounds per square inch.

He states, however, that by reason of imperfect calipering of orifices, and possible error incident to measurement of discharge, his values of co-efficient of discharge "may be in error as much as 3 or possibly 4 per cent." They thus are in general agreement with the results obtained by the writer, and are of interest since the heads under which Mr. Smith experimented were exceptionally great.

The tables giving discharge of nozzles corresponding to various pressures which are in general use, and which, copied and condensed into various shapes, are found in the hand-books of most pump makers and in various treatises on hydraulics and water supply, are those by George A. Ellis, C. E., formerly City Engineer and Water Registrar of Springfield, Mass.

Prior to the publication of these tables by Mr. Ellis there was no information relating specially to hose streams available in form convenient for practical use. The remarkably convenient form in which Mr. Ellis presented his tables has made them very popular; but the experiments on which they were based seemed to have been defective, from causes which do not appear, as the value adopted for co-efficient of discharge was 82 per cent.,* a result at variance with experiments of Weston, Smith and the writer, and also at variance with the values which the

* See G. A. Ellis' "Fire Streams," published by Clark W. Bryan, Springfield, 1878, page 20.

TABLE No. 2.

Co-efficient of Discharge of Smooth Nozzles of Similar Size but Different Form.

Mark.	Date of Experiments.	Time. H.	Time. M.	Approximate average Temperature of Air, Fahr.	Temperature Water, Fahr.	Nominal Size.	Kind of Nozzle.	Actual Diameter of Orifice, inches.	Observed Pressure at Base of Play-Pipe, pounds.	Actual Discharge, gallons per minute.	Corr. for Head due Vel past Piez., lbs.	Static Pressure, pounds.	Theoretical Velocity due Pressure, feet per second.	Theoretical Discharge, gallons per minute.	Co-efficient of Discharge.	Mean Value Co-efficient.
(A)	.....	.....	.....	.....	71 deg.	1½ inches.	Ordinary Smooth Cone..	1.126	.....	.....	.....	.....	.....	.....	.....	.976
Above nozzle being ordinary form, mean value of co-efficient is brought over from Table No. 1, for comparison. In this test, nozzle was on conical pipe shown in Fig. 13.																
The following is for the identical nozzle A, but tested on B. W. H. Flexible pipe shown in Fig. 26.																
(A)	Sept. 27, A.M.	10	41	65 deg.	62	1⅝	Same Nozzle.....	1.126	39.97	238.9	1.63	41.60	78.66	244.0	.979	.978
	"	10	33	65	62	1⅝	" "	1.126	30.02	207.0	1.26	31.28	68.20	211.7	.978	
The following nozzle was of precisely same form as A, except that corner at junction of small end of cone and straight part was rounded off. See Fig. 16.																
(B)	Sept. 25, P.M.	5	48	55	63	1⅝	Smooth Cone.....	1.126	39.97	238.5	1.63	41.60	78.66	244.1	.976	.976
	"	5	36	55	63	1⅝	" "	1.126	30.11	206.9	1.24	31.35	68.28	211.9	.976	
The following nozzle was precisely the same form as A, except that straight part of nozzle was cut off close to small end of cone. See Fig. 17.																
(C)	Sept. 25. A.M.	3	28	60	63	1⅝	Smooth Cone.....	1.125	40.52	239 9	1.66	42.18	79.20	245.4	.977	.977
	"	3	36	60	63	.....	.....	1.125	30.08	206.7	1.24	31.32	68.24	211.4	.978	
The following is the same nozzle A with a small hollow cone inserted to precisely fill enlargement next end of play-pipe and make waterway smooth. See Fig. 15.																
(D)	Oct. 10, P.M.	4	33	42	56	1⅝	Cone A, etc.....	1.126	40.09	237.8	1.63	41.72	78.78	244.5	.973	.971
	"	4	39	42	56	.....	.....	1.126	30.09	205.3	1.23	31.26	68.19	211.6	.970	

For next nozzle see Fig. 14. This nozzle was tested on straight cylindrical brass play-pipe, 30 inches long, inside very smooth.

E	Sept. 27, P.M	5	40	62	62	1⅛	Large Unif. Acceleration	1.133	44.80	254.1	1.85	46.65	83.29	261.7	.971	.971
	"	5	36	62	62	.....	" "	1.133	40.04	241.0	1.67	41.71	78.76	247.5	.974	
	"	5	32	62	62.	.....	.....	1.133	30.13	208.0	1.26	31.39	68.32	214.7	.969	

See Fig. 18 for the following. This nozzle was tested on taper play-pipe 30 inches long, 2½ inches diameter at butt, 1¾ inches inside diameter at throat, and with "rifle" blades inserted as shown in Fig. 18.

(F)	Aug. 23, P.M.	4	01	64	69	1⅛	Small Unif. Acceleration.	1.122	51.99	268.4	2.07	54.06	89.67	276.34	.971	.971

The following nozzle was tested on same conical pipe shown in Fig. 13.

(H)	Sept. 22, P.M.	1	32	59	64	1¼	Short "Choke Bore"....	1.260	39.95	300.5	2.60	42.55	79.56	309.20	.972	.971
	"	1	28	59	64	.....	"	1.260	29.78	258.8	1.91	31.69	68.66	266.84	.970	

The following nozzle was slightly converging to the very end, which tends to make co-efficient slightly smaller than the preceding ones.

(I)	Oct. 10, P.M.	5	12	40	56	1¼	Large Unif. Accel. with end piece removed.	1.262	40.02	300.2	2.60	42.62	79.62	310.4	.967	.967
	"	5	17	.....	56	.....	.....	.....	30.11	260.4	1.94	32.05	69.05	269.2	.967	

The following is the nozzle shown by the full lines in Fig. 23, and was tested on the play-pipe shown in same figure. The lower value of co-efficient is owing to increased friction, due narrowness of waterway near down-stream end of play-pipe, this being a cheap, light-weight pipe.

(J)	Sept. 27, A.M.	10	12	65	62	1¼	Smooth, with narrow throat.	1.250	44.87	305.2	2.68	47.55	84.10	321.7	.949	.946
	"	10	06	65	62	.....	"	1.250	39.89	286.9	2.34	42.23	79.25	303.1	.946	
	"	9	52	65	62	.....	"	1.250	29.99	248.2	1.78	31.77	68.73	262.9	.944	
	"	9	34	65	62	.....	"	1.250	20.00	203.0	1.20	21.20	56.15	214.8	.945	

The following experiment is upon same nozzle and play-pipe as A, but obstructed by inserting hollow cone, which formed a sharp cornered ridge, projecting into waterway one-tenth inch, as shown in Fig. 22.

(K)	Oct. 10, P.M.	4	21	42	56	1⅛	Nozzle A, obstructed....	1.126	40.06	235.8	1.60	41.66	78.71	244.3	.965	.961
	"	4	26	42	56	.....	.....	1.126	30.04	202.4	1.19	31.23	68.15	211.5	.957	

There is an uncertainty of, say, $\frac{3}{1000}$ inch in diameter of the following nozzle, by reason of its "straight part" being not exactly cylindrical or of uniform diameter throughout length, but co-efficient must have been actually .980, at least.

(L)	Oct. 10, P.M.	4	46	42	56	1⅛	Bottle shaped.....	1.127	39.96	241.0	1.67	41.63	78.68	244.6	.985	.986
	"	4	52	42	56	.....	.....	1.127	29.79	208.5	1.26	31.05	67.96	211.3	.987	

text-books of Weisbach and others indicate as probable. To get the true discharge 18¾ per cent. should be added to the discharges for smooth nozzles stated in the Ellis tables and their numerous reproductions.

Table No. 2 is of especial interest as showing the small effect which change of form has on the co-efficient of discharge; and it is the results in this table which furnish the basis for the statement that water under high pressures may be measured with extreme accuracy by means of smooth hose nozzles of ordinarily good construction, and that this method of measurement, providing an accurate pressure gauge is at hand, and is connected directly to base of play-pipe by a suitable piezometer, is equal to all the requirements of a pumping engine test, and equal in accuracy to the ordinary weir measurement.

It is of interest in this connection to compare the agreement of these co-efficients with the agreement between the original weir experiments. Thus see "Lowell Hydraulic Experiments," page 125, for instance; also Smith's "Hydraulics," page 93 *et seq.* It will be seen that the agreement is more close for the nozzles than for the weirs. It should be borne in mind, however, that the weir experiment was a vastly more difficult undertaking, and the attainment of such a degree of precision when dealing with such large quantities as used by Mr. Francis and Messrs. Fteley and Stearns, was a very remarkable achievement. The field of usefulness for the nozzle, as a means of gauging, is a restricted one, but in this restricted field it has, I believe, a very high value.

A Committee of the American Society of Mechanical Engineers has now under consideration recommendations designed to secure uniform accurate practice in the testing of pumping engines. The well known expert steam engineer, Mr. George H. Barrus, as a member of the Committee having this matter directly in charge, recently presented a paper to the Boston Society of Civil Engineers, in which it was recommended that for the many situations where it was inexpedient to erect a weir, the pump itself be used as a water meter, by correcting its plunger displacement for clearance and slip, and repeatedly measuring stroke in cases where its length is not positive. To me this appears rather too uncertain a method for general application in important cases, and it is therefore suggested that for tests in connection with direct pumping systems or other cases where the erection of a weir is inconvenient, the discharge may be measured by nozzles with fully equal accuracy.*

* The use of the Venturi meter recently invented by Mr. Clemens Herschel, M. Am. Soc. C. E., is also to be recommended as a method much preferable to using the pump itself as a water meter. (Transactions, Vol. XVII, page 228, and Vol. XVIII, page 133.)

To go a step further, it would be easy and not expensive to construct and set up in a pumping station a conveniently portable pressure box of plate iron with outlets having rounded entrance, to which any desired number of play-pipes and nozzles could be screwed on. Under 80 pounds pressure four 1¼-inch nozzles, connected direct without hose, would discharge the full capacity of a pump discharging "two and one-half-million gallons per 24 hours;" and if such a device were permanently attached to the pump it would, in connection with some tables which could be readily computed, furnish an inexpensive, quick and exceedingly valuable means for enabling the engine-man to determine at any time whether the per cent. of loss of action in his pump was getting too large, by wearing of valves or other cause.

The difficulty which will first suggest itself and which may possibly render this means of measurement sometimes impracticable, is that the irregularities of pressure due to the pulsations of the pump would affect the accuracy of the gauge readings. This can probably be obviated if a pressure box is used, by an air chamber of moderate size on the pressure box, in connection with the throttle valve between the box and the pump, which should be provided for regulating or adjusting the required back pressure on pump. Moreover, it may be remarked that 5 per cent. pulsation or variation in pressure on a nozzle makes very much less proportional difference in its discharge than does 5 per cent. variation in depth over a weir.*

With regard to the gauge by which pressure on nozzle should be measured in thus testing delivery of a pump, it may be said that while an open mercury column is the best, yet a first-class Bourdon gauge will measure the water delivered by the pumping engine just as well as it will the steam supplied to the engine, and in fact will do it better; for an error of one pound at a pressure of 100 pounds upon the nozzle will cause an error of only one-half of 1 per cent. in discharge.

To avoid possible misapprehension, we will state here that the tables at the end of this paper, pages 444–447, entitled "Pump Inspection

* November, 1889. I have since devised and now have under construction an arrangement somewhat similar to that shown in Figs. 43 and 44, with piezometer like Fig 2, located a little above point *B*, Fig. 44, which will probably not weigh more than 50 to 75 pounds, or cost more than sixty dollars exclusive of gauge; a single one of which will, I think, serve to gauge the discharge of a pumping engine throwing two million gallons per twenty-four hours with an accuracy fully equal or superior to the best weir measurement. This device can be calibrated once for all, can be moved from place to place as occasion demands, and as its setting up involves only the laying of three short lines of common rubber lined hose and requires no foundation, it can be set up and adjusted ready for use in half an hour. This promises to be of so much value as a means of gauging that a communication will probably be made to the Society regarding what test may determine as to its practicability or lack of practicability.

Tables," are not intended for such accurate measurements as just referred to. These are intended for the quick and ready use of the Waterworks Superintendent, Insurance Inspector or other every-day use, where absence of accurate piezometric contrivances does not admit of measuring pressure close to base of play-pipe. The variation in loss of head, in different pieces of hose, makes such a gauging as by Table B No. 1 uncertain to the extent of, say, in general, 5 per cent.; while by properly measuring the pressure directly at base of play-pipe, a result certain within one-half of 1 per cent. may be attained.

I desire to state here that this matter of the degree of accuracy attainable in measuring flow of water by means of nozzles was not one of the main objects of the experiments, but has developed itself incidentally as the results were computed; otherwise care would have been taken to design, with a special view to use in gauging, certain standard forms easily reproduced, and to determine the corresponding co-efficients of discharge.

The writer has since the experiments designed a standard form of play-pipe for ordinary use in mill fire protection equipments, which is now kept in the market as a matter of regular stock and can be procured of almost any maker of fire department supplies. This is shown in Fig. 7. For this, with nozzles $1\frac{1}{2}$ or $1\frac{1}{4}$ inches in diameter, of ordinary good finish, co-efficient of discharge may be taken as .977, with very great confidence that this will not be more than one-half of one per cent. in error. A suitable piezometer and gauge must be used, however,

Proposed Standard Nozzle.

Fig. 7.

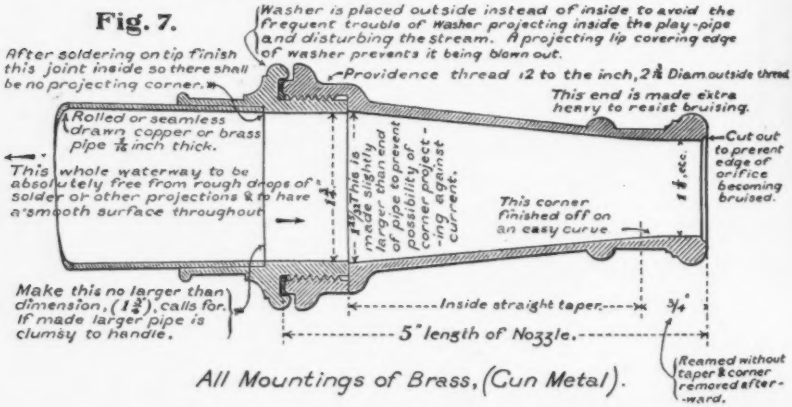

Washer is placed outside instead of inside to avoid the frequent trouble of Washer projecting inside the play-pipe and disturbing the stream. A projecting lip covering edge of washer prevents it being blown out.
After soldering on tip finish this joint inside so there shall be no projecting corner.
Providence thread 12 to the inch, 2¾ Diam outside thread
This end is made extra heavy to resist bruising.
Rolled or seamless drawn copper or brass pipe ⅛ inch thick.
Cut out to prevent edge of orifice becoming bruised.
This whole waterway to be absolutely free from rough drops of solder or other projections & to have a smooth surface throughout
This is made slightly larger than end of pipe to prevent possibility of corner projecting against current.
This corner finished off on an easy curve
Make this no larger than dimension, (1⅜), calls for. If made larger pipe is clumsy to handle.
Inside straight taper
¾
5" length of Nozzle.
All Mountings of Brass, (Gun Metal).
Reamed without taper & corner removed afterward.

TABLE No. 3.—Co-efficient of Discharge of Ring Nozzles.

Mark.	Date of Experiment.	Time. H.	Time. M.	Approx. Av. Temp. Air, deg. Fahr.	Temperature, Water, deg. Fahr.	Nominal Size, Inches.	Kind of Nozzle.	Actual Diameter of Orifice, Inches.	Observed Pressure at Base of Play-pipe, Pounds.	Actual Discharge, Galls. per Min.	Corr. for Head due Vel. past Piez., lbs.	Static Pressure, Pounds.	Theoretical Velocity due Pressure, Feet per Second.	Theoretical Discharge, Gallons per Minute	Co-efficient of Discharge.	Mean Value Co-efficient.	Remarks.
(h)	Sept. 10, A.M.	8	41	70	69	1 1/2	Square Ring	1.107	58.06	208.8	1.26	59.32	93.94	281.8	.741	.742	All these nozzles excepting (j) and (o) were each attached to the 30-inch play-pipe shown in Fig. 13 when tested, and pressure gauge was connected to piezometer at base of play-pipe, as shown in the same figure. For description of this play-pipe see Table No. 1.
	Sept. 8, A.M.	11	19	67	69	1 1/2	"	"	49.49	192.8	1.08	50.57	86.72	260.2	.741		
	Sept. 22, A.M.	12	00	59	64	1 1/2	"	"	45.03	183.7	.98	46.01	82.73	248.2	.740		
	"	11	49	59	64	1 1/2	"	"	30.11	150.2	.64	30.75	67.62	202.9	.740		
	"	11	42	59	64	1 1/2	"	"	25.05	137.8	.54	25.59	61.69	185.1	.744		
	"	11	32	59	64	1 1/2	"	"	19.96	123.3	.44	20.40	55.08	165.2	.746		
(i)	Sept. 10, A.M.	.....		70	69	1 1/2	Square Ring	1.250	52.90	253.4	1.84	54.74	90.23	345.1	.734	.736	Nozzles (j) and (o) were each attached to play-pipe shown in Fig. 14. The nozzles themselves are shown in Figs. 31 and 32.
	Sept. 22, A.M.	11	19	59	64	1 1/2	"	"	45.48	234.8	1.58	47.06	83.66	320.0	.733		
	"	11	14	59	64	1 1/2	"	"	30.16	191.6	1.06	31.22	68.15	260.6	.735		
	"	11	7	59	64	1 1/2	"	"	24.99	174.6	.87	25.86	62.02	237.2	.736		
	"	11	0	59	64	1 1/2	"	"	20.07	157.4	.70	20.77	55.58	212.6	.740		
(j)	Sept 27, A.M.	9	40	65	62	1 1/2	Sq. 2 1/2 Cap	1.250	49.91	188.6	1.03	40.94	78.02	298.4	.632	.634	Nozzles (k), (i), (m), (n) are varieties found regularly in the market.
	"	9	36	65	62	1 1/2	"	"	30.06	164.7	.76	30.82	67.71	259.0	.636		
(k)	Oct. 10, P.M.	3	45	42	56	....	Sq. Ring with Disch. Equiv. to 1 1/2 smooth.	....	1.314	40.04	242.9	1.70	41.74	78.79	333.0	.729	.729
	"	3	55	42	56	....			"	30.01	210.6	1.28	31.29	68.22	288.4	.730	
(l)	Oct. 10, P.M.	.....		42	56	1 3/16	Square Ring	1.188	40.16	236.1	1.60	41.76	78.81	272.3	.867	.866	Nozzles (l), (p) and (q) were manufactured for these experiments, with a view to determining effect of slight contraction on character of jet.
	"	2	58	42	56	1 3/16	"	"	30.12	204.0	1.10	31.32	68.24	235.8	.865		
(m)	Sept. 22, P.M.	12	28	59	64	1 1/8	Undercut Ring	1.128	44.87	186.6	1.00	45.87	82.59	257.3	.725	.723	Nozzles (n) and (o) were manufactured for these experiments, with a view to determining effect of contraction on character of jet.
	"	12	24	59	64	1 1/8	"	"	40.00	174.7	.89	40.89	77.99	242.9	.719		
	"	12	18	59	64	1 1/8	"	"	35.19	165.2	.78	35.97	73.14	227.8	.725		
	"	12	15	59	64	1 1/8	"	"	29.75	151.3	.65	30.40	67.24	209.5	.722		
	"	12	6	59	64	1 1/8	"	"	20.02	124.3	.47	20.49	55.20	172.0	.723		
(n)	Sept. 22, P.M.	12	56	59	64	1 1/4	Undercut Ring	1.250	44.98	225.6	1.47	46.45	83.12	317.9	.710	.713	In Nozzle (k) the projection of shoulder was greater than in (h) or (i), which accounts for the less value of co-efficient.
	"	12	52	59	64	1 1/4	"	"	39.89	213.1	1.32	41.21	78.29	299.5	.712		
	"	12	43	59	64	1 1/4	"	"	30.11	185.8	1.00	31.11	68.02	260.2	.714		
	"	12	34	59	64	1 1/4	"	"	19.88	151.5	.67	20.55	55.29	211.5	.716		
(o)	Sept. 27, A.M.	9	21	65	62	1 1/4	Undercut 2 1/2 Cap	1.251	40.09	173.5	.85	40.94	78.02	298.9	.580	.582	In measuring discharge of (j) a packing washer, as shown in Fig. 31, was inadvertently used of diameter smaller than main pipe.
	"	9	15	65	62	1 1/4	" "	"	30.03	150.8	.65	30.68	67.54	258.8	.583		
(p)	Sept. 22, P.M.	1	5	59	64	1 1/4	Taper Ring	1.247	39.90	247.1	1.76	41.66	78.71	297.7	.830	.830	
	"	1	1	59	64	1 1/4	"	"	29.81	213.7	1.33	31.14	68.05	257.4	.830		
(q)	Sept. 22, P.M.	1	22	59	64	1 1/8	Short "Choke Bore"	1.131	45.09	231.0	1.54	46.63	83.27	260.8	.885	.886	
	"	1	17	59	64	1 1/8	"	....	40.12	217.4	1.38	41.50	78.57	246.0	.884		
	"	1	13	59	64	1 1/8	"	....	29.88	188.7	1.03	30.91	67.81	212.4	.888		

to insure this degree of accuracy in the gauging, and diameter of outlet must be callipered with exactness and care.

As a means of gauging water and for diameters of an inch or two, the nozzle has a very great advantage in accuracy over the square edged orifice, since the edges of the latter are never absolutely square and the slight rounding makes the measurement of its diameter uncertain to a degree which may readily introduce an error of 1 per cent. in computation of discharge.

Discharge of Ring Nozzles.

(See table on page 333 *and figures on pp.* 323 *and* 324.*)*

The preceding table shows that for the forms of ring nozzle commonly met in practice, viz., nozzles (*h*) and (*i*), the co-efficient of discharge may be taken as .74. Thus we see that for the ring nozzle, as for the smooth nozzle, the Ellis tables are seriously in error; they being based on a value of .64 for the co-efficient. To get the true discharge $15\frac{5}{8}$ per cent. should be added to that given by the Ellis tables. In nozzle (*k*) the shoulder is rather deeper, and one with shoulders deeper than this is seldom found in practical use. The nozzles *M* and *N* are of a form believed by some good firemen to throw a better jet than any other form, and are thus frequently met in practice. The co-efficient is seen to differ less from the square ring than might perhaps have been expected. Nozzles (*l*), (*j*) and (*o*) are not styles in practical use, but were constructed for the purpose of investigating the effect of various degrees of contraction upon smoothness and reach of jet.

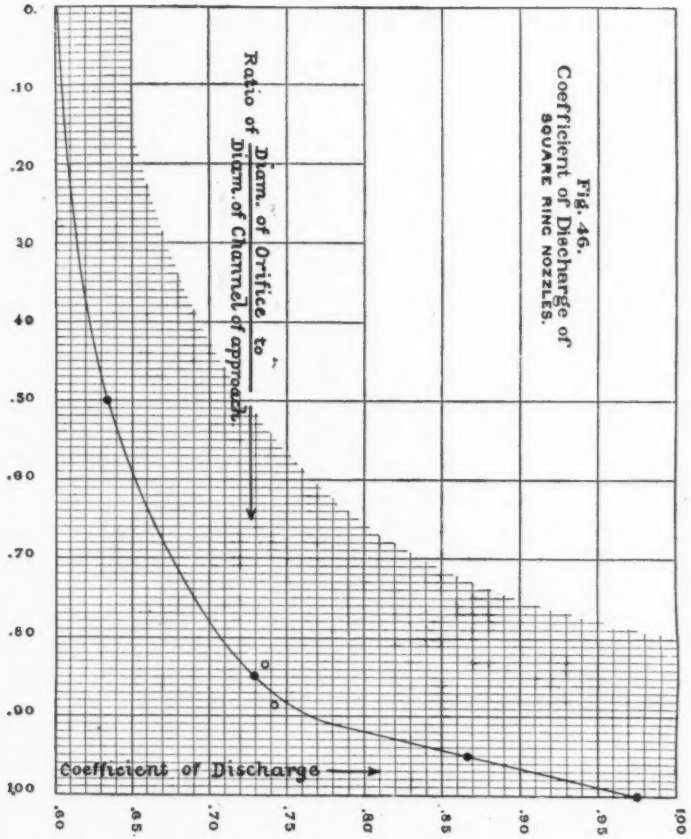
The results given in Table No. 3 cover quite a range of contractions, and are of some interest in helping define the influence of ratio between diameter of orifice and diameter of channel above it, upon the co-efficient of contraction.

This is a subject on which precise information is less complete than desirable. About the only published data which the writer now recalls is that referred to in "Weisbach's Mechanics" (see Cox's "Weisbach," Vol. I, page 841).

Professor Weisbach there gives certain corrections for incomplete contraction, based upon experiments of his own, which he says can be applied with great accuracy. These do not fit the experiments in Table No. 3 very well, differing from 1 to $7\frac{1}{2}$ per cent., as will be seen by table at top of page 336.

The results of these experiments on contraction are shown graphi-

cally by Fig. 46, and a curve is there drawn which, until the results of more complete experiments are presented, may be found of use in indicating proper value of co-efficient for similar problems. In this connec-



tion a study of the curves of distribution of velocity are of interest. (See Figs. 61 and 62.) Perhaps for a diaphragm at end of a long tube of uniform width, the co-efficient might be different.

This subject and that of effect of diaphragms in pipes are fruitful ones for investigation in detail, and might be taken up with advantage

in a well equipped hydraulic laboratory, such as that proposed in the new building of the Massachusetts Institute of Technology, and the ratios accurately determined once for all.

INFLUENCE OF RELATIVE AREA OF ORIFICE TO AREA OF CHANNEL OF APPROACH IN MODIFYING CO-EFFICIENT OF DISCHARGE OF NOZZLE.

Nozzle.	Diameter Orifice.	Diameter Channel.	Ratio Diameters.	Ratio Area of Orifice to Area of Channel.	Actual Co-efficient Discharge.	Ratio to Co-efficient Discharge for Complete Contraction = 0.60.	Weisbach's Ratio.	Co-efficient Discharge to be Expected from Weisbach's Ratio.	Actual Discharge less than per Weisbach.
									Per cent.
A, B, etc.	1.126	.....	1.00	1.00	.975	1.66	1.63		
**(l)*	1.188	1.25	.950	.903	.866	1.443	1.475	.885	2.1
†(*h*)	1.107	1.25	.886	.785	.742	1.237	1.337	.802	7.5
†(*i*)	1.250	1.50	.833	.694	.736	1.227	1.255	.753	2.3
‡(*k*)	1.314	1.55	.848	.719	.729	1.215	1.275	.765	4.7
§(*j*)	1.250	2.50	.500	.250	.634	1.057	1.045	.627	1.1
						Ratio to Co-efficient, .50			
(*o*)	1.251	2.50	.500	.250	.581	1.162			

DISCHARGE OF SIAMESE NOZZLES.

The experiments on discharge of Siamese nozzles (see Table No. 4) are of no such general interest as the results in the preceding tables, but are merely of value as giving definite knowledge in reference to one special form of apparatus. The values found are of some general interest, however, as showing effect of various projections of shoulder upon contraction of jet. Probably had the piezometer been applied directly at base of the straight play-pipe the co-efficient for the smooth nozzle would have been not far from .975; and the less value found (by about 2 per cent.) may be regarded as due to the frictional resistance in the Siamese and elbow.

With nozzle (*s*), 1¼ inch diameter, there was less relative loss in Siamese and elbow, and the co-efficient is seen to approach the values in Tables Nos. 1 and 2 very nearly.

* Edges very sharp and square.

† This co-efficient would naturally be a little large, as shoulders are not in a perfect plane, but incline slightly in direction of current.

‡ Excellent experiment. Shoulders very sharp and square.

§ Edges very sharp and square.

TABLE No. 4.

Co-efficient of Discharge of Large Nozzles Combined with Siamese, etc.

Mark.	Date of Experiments.	Time. H.	Time. M.	Approx. Av Temp. Air, deg. Fahr.	Temperature, Water, deg. Fahr.	Nominal Size, inches.	Kind of Nozzle.	Actual Diameter of Orifice, Inches.	Observed Pressure at entrance to Siamese, Pounds.	Actual Discharge, Gallons per Minute.	Cor. for Head due Vel. past Piez., lbs.	Static Pressure, Pounds.	Theoretical Velocity due Pressure, Feet per Second.	Theoretical Discharge, Gallons per Minute.	Co-efficient Discharge—combined Siamese and Nozzle.	Mean Value Co-efficient.	
(r)	Sept. 21, A.M.	10	44	60	64	2	Cone on Small Siamese...	2.014	40.10	707.2	1.60	41.70	78.75	782.0	.904	.908	
	"	10	39	60	64	2	" " ...	"	34.92	663.2	1.42	36.34	73.52	730.0	.908		
	"	10	30	60	64	2	" " ...	"	29.76	613.7	1.21	30.97	67.86	673.8	.911		
The play-pipe on which the above was tested is not shown in the drawings. It was a straight cylindrical pipe, 3 inches diameter for whole length. Bulb and elbow were also 3 inches diameter. Except for this smaller waterway, it was almost exactly like Figs. 43 and 44. The smaller co-efficient is due extra friction in small waterway. The following nozzles were tested on pipe shown in Fig. 44. Nozzle is shown on larger scale in Fig. 37.																		
(s)	Sept. 21, A.M.	12	00	60	64	2	Cone on Big Siamese.....	2.023	40.21	755.8	1.81	42.02	79.05	792.0	.954	.953	
	"	11	53	60	64	2	" "	"	30.00	651.9	1.37	31.37	68.30	684.3	.953		
(t)	Sept. 22, A.M.	10	05	57	64	1 13/16	Cone on Big Siamese.....	1.762	39.98	575.2	1.07	41.05	78.14	593.9	.968	.969	See Fig. 42.
	"	9	57	57	64	1 13/16	" "	"	35.09	538.5	.93	36.02	73.19	556.3	.968		
	"	9	50	57	64	1 13/16	" "	"	30.07	500.3	.79	30.86	67.75	514.9	.972		
Co-efficient of the last nozzle is larger, probably due to relatively smaller loss in elbow, etc.																	
(u)	Sept. 21, P.M.	3	43	60	64	2	Square Ring on 2 1/2-in. Noz.	2.000	39.87	587.4	1.11	40.98	78.07	764.5	.768	.767	See Fig. 38.
	"	3	29	60	64	2	" " ..	"	29.95	508.2	.82	30.77	67.66	662.5	.767		
(v)	Sept. 21, P.M.	4	01	60	64	2	Square Ring on 2 1/4-in. Noz.	2.000	34.89	475.8	.71	35.60	72.77	712.6	.668	.668	See Fig. 40.
	"	3	53	60	64	2	" " ..	"	29.84	441.2	.62	30.46	67.31	659.1	.669		
(w)	Sept. 21, P.M.	5	38	60	64	2 1/2	Square Ring on 2 1/4-in. Noz.	2.122	34.98	657.9	1.39	36.37	73.54	810.6	.812	.810	See Fig. 41.
	"	4	57	60	64	2 1/2	" " ..	"	30.14	608.6	1.19	31.33	68.26	752.4	.809		
(x)	Sept. 21, P.M.	4	48	60	64	2	Unc. Ring on 2 1/4-in. Nozzle.	2.008	34.98	552.4	.99	35.97	73.14	721.9	.765	.762	See Fig. 39.
	"	4	36	60	64	2	" " ..	"	30.05	507.6	.82	30.87	67.75	668.7	.759		
The following is the same as Fig. 38, with smaller ring removed.																	
(y)	Sept. 21, P.M.	5	30	60	64	2 1/2	Unc. Ring on 2 1/4-in. Nozzle	2.113	34.78	654.8	1.37	36.15	73.33	801.5	.817	.815	
	"	5	21	60	64	.....	.....	.....	29.82	603.3	1.16	30.98	67.88	741.9	.813		

NOTE.—These values are in proper shape for practical use, but in comparing them with co-efficients for ordinary nozzles and play-pipes, the fact that these values clude effect of loss due friction in the Siamese and the 45 degree elbow must be kept in mind. All nozzles in this table were tested on a Siamese, and pipe similar to at shown in Figs. 43 and 44. Piezometer was connected immediately back from Siamese.

Loss of Pressure by Friction in Hose.

This was determined for fourteen different kinds of 2½-inch hose intended to represent all the typical kinds in ordinary use. No attempt was made to experiment upon all the different makes, sizes and brands in the market, these being so very numerous as to make such a work impracticable.

In each kind of hose tested, the friction loss was determined with inch, 1⅛, 1¼ and 1⅜-inch smooth nozzles attached, and in nearly all kinds it was also determined with ⅞, ⅞ and 1½-inch nozzles.

The hydrant pressure in the various experiments varied from 15 to 125 pounds per square inch, and the delivery of the hose from about 50 to 325 gallons per minute; the corresponding mean linear velocity in some of the kinds of hose thus ranging from 3 to about 21 feet per second.

The loss of pressure by friction was found to follow the common theory of being proportional to the square of the discharge closely enough for nearly all practical purposes; but the fact that there was a slight divergence from this law was also clearly shown. (See plotted curves, Fig. 48. The full lines show mean results of the experiments. The dotted lines are mathematical curves of squares drawn through the 240-gallon point.)

The length of lines of hose experimented upon varied from 50 to 325 feet, and as was to be expected as a matter of course, the friction loss was found to be substantially proportional to the length; that is, the friction loss in a line 300 feet long was almost exactly three times that in a line 100 feet long. (See plotted curves; note, for instance, with Sample K, how closely the observations on loss per 100 feet coincide, though lines vary in length.)

The general method of making these experiments (see figures on page 315, also Fig. 50) was to lay out a line of hose of convenient length, which might be anywhere from 50 to 325 feet, but usually was 150 or 300 feet, in a straight line upon a fairly smooth plank walk or platform which sloped 1 foot in 100 down toward nozzle. Immediately alongside the plank walk or platform on which the hose was laid were three hydrants about 100 feet apart, and hose was connected to whichever came most convenient for the length under experiment. To the downstream end of this straight line of hose the play-pipe was attached and bent upward at an angle of 30 degrees. This vertical bend in the hose

was made on curve of 10 feet radius by the hose lying in a box or trough of that form. To the up-stream end of the straight line of hose a 25-foot length of hose like sample *C* was attached, and its upper part curved around in whatever way was necessary to connect it to hydrant, though care was taken that this curve should be of not less than about 4 or 5 feet radius.

Figs. 1 to 6 illustrate various features pertaining to the arrangement of the apparatus. Fig. 2 illustrates the couplings used for measuring the pressure within the hose, and already described.

There were two of these piezometer couplings used with each line of hose. The customary location of the up-stream one was in the straight line of hose 25 feet away from the hydrant, and of the down-stream one close to the base of play-pipe, though occasionally they were connected into the line of hose at other points to make sure that there was no local disturbance at the points first named.

The two mercury gauges by which pressures were measured, already described, were fastened in most cases to adjacent brick walls and connection made to the piezometers just described by from 8 to 15 feet of rubber tubing. Much care was taken to support this tubing on an even incline up toward gauge, so air bubbles should not lodge and affect results, and immediately before each set of experiments the waste cock in the gauge was opened for a few minutes so that the swift current of water through this small tube should effectually wash out any possible bubbles. The cocks at ends of this tubing were generally kept nearly wide open during an experiment, for I believe small errors are often introduced by the too close throttling of a gauge as often practiced to check oscillations.

As a check, Bourdon test gauges were, in several experiments, connected directly to the piezometer without the intervention of so much tubing. All these checks only tended to confirm the accuracy of the method generally followed.

The line of hose being stretched out in a straight line along the platform and the water let into it, then when all was in a condition of steady flow the experiment on friction loss was made. One observer, with a helper who swung the play-pipe, measured the gallons per minute discharged, as described on page 314, the two other observers meanwhile noting at half-minute intervals the readings of the pressure gauges at each end of the sample of hose under experiment.

In most cases the water was supplied from the city water-works, but in certain experiments, designed to show the effect of a very high pressure within the hose upon the friction, the water was supplied by the mill fire pumps. When water from the city reservoir was used, the fluctuations of pressure did not often exceed ½ or ¾ pound in the course of an experiment, or 0.1 to 0.2 pound between successive observations; while, when supply came from pump, the unsteadiness of pressure often made a difference of two or even three pounds at up-stream gauge or of half this amount at the down-stream gauge, but at this down-stream gauge there was seldom a difference of ½ pound between successive readings.

As each experiment on friction loss was computed from the average of five to ten independent observations taken simultaneously at the two ends of the hose experimented upon, I feel confident that the error in determination of pressure lost by friction between the two ends of any sample did not exceed ½ pound, and in general was much less than this.

Various rates of delivery were secured by attaching nozzles of different sizes to the play-pipe, the hydrant gate being generally opened to its full extent. With the exception of the 25-foot piece ordinarily used next the hydrant, all hose experimented upon was in the ordinary 50-foot commercial lengths, and all was fitted with ordinary expanded ring couplings (see Fig. 52), thus giving a waterway of the full nominal diameter of the hose. Care was taken in all cases that the hole in the elastic washer used for packing the joint should be of full size of bore of coupling. The following table (No. 5) gives results of the experiments. It is to be remarked that while temperature of water as given is probably correct within 1 or 2 degrees, the temperature of air was observed with less care, and as it varied at different parts of the line, the figure given may vary from the true mean by 5 degrees.

The results on the several sheets of Table No. 5 were plotted on cross section paper on scale of 1 centimeter = 1 pound per square inch loss per 100 feet, and 2 millimeters = 1 gallon per minute. A photo-engraving on small scale (see Fig. 48) is given of a tracing from about half these curves; the remainder having been omitted from this plotting simply to avoid confusion. Table No. 6 gives a comparison of the relative loss found in the different kinds of hose; the values there given having been taken from the plottings of Table No. 5 just mentioned.

TABLE No. 5.

EXPERIMENTS ON FRICTION LOSS IN FIRE HOSE. **Sample L: 2½-inch Ordinary Unlined Linen Fire Hose.** (Ross, Turner & Co.'s make.) Actual average Internal Diameter of Hose, 2.60 inches; Diam. measured under Pressure in Experiment 7. Actual average Internal Diameter of Couplings, 2.50 inches.

DATE.—1888.	Time. H.	Time. M.	Temperature, Fahr. Air (approx.)	Temperature, Fahr. Water.	No. of Experiment.	Pressure Gauge, Corrections, due Level, etc., Used. Up Stream.	Pressure Gauge, Corrections, due Level, etc., Used. Down Stream.	Observed Pressures at Piezometers (Corrected). (Lbs. per sq. in.) Up Stream.	Observed Pressures at Piezometers (Corrected). (Lbs. per sq. in.) Down Stream.	Length of Hose between Piezometers. (Feet.)	Loss of Pressure per 100 feet in Length of Hose.	Average Pressure in Hose.	Actual Discharge of Nozzle as Measured in Tank.	Mean Quantity Flowing through Hose, Corrected for Leaks (Gal. per min.)	Nozzle Used. Size.	Nozzle Used. Kind.	Pounds increased loss of pressure per 100 feet due sinuosity.	Per cent. increased loss of pressure due sinuosity.
Hose laid straight; water supplied from City Reservoir.																		
August 22—A.M	11	52	76	72	1	+0.35	+0.15	12.94	10.47	153.5	1.61	13	54.4	54.7	¾	smooth (a)		
"	11	38	.....	72	2	"	"	29.23	23.79	154.2	3.53	28	81.5	81.8	"	" (a)		
"	11	23	.....	72	3	"	"	52.04	42.52	154.9	6.15	49	108.1	108.4	"	" (a)		
"	8	45	70	72	4	"	"	66.62	54.43	"	7.86	62	122.8	123.1	"	" (a)		
"	9	00	.....	72	5	"	"	65.72	46.68	"	12.29	58	156.6	156.9	"	" (b)		
"	9	14	.....	72	6	"	"	65.35	39.40	"	16.75	54	185.4	185.7	1	" (c)		
"	9	25	.....	72	7	"	"	63.46	30.88	"	21.03	49	209.4	209.7	1¼	" (A)		
August 21—P.M	5	37	65	72	8	+0.30	+0.10	62.06	23.59	"	24.84	44	226.6	227.1	1¼	" (h)		
August 22—A.M	9	37	75	72	9	+0.35	+0.15	61.97	23.81	"	24.63	44	228.1	228.4	1¼	" (h)		
"	9	52	.....	72	10	"	"	60.93	18.34	"	27.50	41	241.8	242.1	1¼	" (f)		
"	10	04	.....	72	11	+0.42	+0.22	59.60	11.64	"	30.96	37	257.8	258.1	$1\frac{55}{100}$	nozzle off		
Same hose laid straight, but supplied by rotary fire pump under higher pressures.																		
August 22—P.M	4	23	70	72	12	+0.35	+0.15	79.29	30.68	155.	31.36	57	258.8	259.1	1¼	smooth (h)		
"	4	10	.....	72	13	"	"	93.71	36.58	"	36.86	67	281.2	281.5	1¼	" (h)		
"	5	08	.....	72	15	+0.42	+0.23	103.98	40.31	"	41.08	74	296.2	296.5	$1\frac{65}{100}$	nozzle off		
"	4	55	.....	72	16	"	"	96.05	18.92	"	49.76	59	328.4	328.7	$1\frac{65}{100}$	"		
Same hose, with natural sinuosity due to its elongation under pressure. Hose was laid straight before admitting water, but under pressure took this sinuous form.																		
August 21—P.M	4	44	67	72	17	+0.30	+0.10	64.75	52.27	154.9	8.06	60	119.8	120.3	¾	smooth (a)	0.51	6.3
"	4	58	.....	72	18	"	"	66.94	46.62	"	13.12	58	156.5	157.0	¾	" (b)	0.81	6.2
"	5	11	.....	72	19	"	"	63.68	29.91	"	21.80	48	205.5	206.0	1¼	" (A)	1.42	6.5
"	5	25	.....	72	20	"	"	62.16	22.95	"	25.31	44	223.2	223.7	1¼	" (h)	1.51	6.0

NOTE.—In Experiments 17 to 20, position of hose was very nearly the same in each experiment. There were thirteen bends in all. Radius varied from 3 feet to 10 feet, but averaged about 5 feet. Average length of curves about 60 degrees of arc. There were no kinks or constrictions at any time.

A comparison of plotting of Experiments 11 and 12 is interesting, as showing small effect that increase of pressure within hose had in modifying friction loss or changing diameter of water-way for this kind of hose.

TABLE No. 5—(*Continued*).—Experiments on Friction Loss in Fire Hose. **Sample K:** 2½-inch Woven Cotton Rubber Lined "Mill" Hose. (Boston Woven Hose Co.'s make.) Average Internal Diameter of Hose measured under conditions of Experiment 28, 2.53 inches.

Date.—1888.	Time. H.	Time. M.	Temperature, Fahr. Air. (approx.)	Temperature, Fahr. Water.	No. of Experiment.	Pressure Gauge, Corrections, due Level, etc., Used. Up Stream.	Pressure Gauge, Corrections, due Level, etc., Used. Down Stream.	Observed Pressures at Piezometers (Corrected). Up Stream.	Observed Pressures at Piezometers (Corrected). Down Stream.	Length of Hose between Piezometers.	Loss of Pressure per 100 feet in Length of Hose.	Average Pressure in Hose.	Actual Discharge of Nozzle as Measured in Tank.	Mean Quantity Flowing through Hose, Corrected for Leaks.	Nozzle Used. Size.	Nozzle Used. Kind.	
Three 50-foot sections of hose laid straight; water supplied from City Reservoir.																	
August 28—A.M	10	14	68	71	21	+0.36	+0.16	12.43	10.56	167.3	1.12	13	54.4	54.4	1"	smooth	(a)
"	9	56	.....	71	22	+0.36	+0.16	28.04	23.63	167.5	2.63	27	81.0	81.0	"	"	(a)
"	9	38	.....	71	23	"	"	51.28	42.75	168.1	5.07	49	108.7	108.7	"	"	(a)
"	9	10	.....	71	24	"	"	68.34	56.96	166.5	6.83	64	125.4	125.4	"	"	(a)
"	11	00	.....	71	25	"	"	42.49	30.88	168.1	6.91	38	126.8	126.8	"	"	(b)
"	10	35	.....	71	26	"	"	66.73	48.15	168.5	11.03	57	159.1	159.1	"	"	(b)
"	11	12	.....	71	27	"	"	64.94	39.87	168.6	14.87	54	186.3	186.3	1	"	(c)
"	11	30	.....	71	28	"	"	63.19	31.29	168.5	18.93	49	211.3	211.3	1¼	"	(A)
"	11	40	.....	71	29	"	"	61.66	24.14	168.3	22.29	44	229.8	229.8	1¼	"	(h)
"	11	48	.....	71	30	"	"	60.42	18.54	168.3	24.88	41	243.6	243.6	1¼	"	(f)
"	11	55	.....	71	31	+0.43	+0.23	59.08	11.85	168.3	28.06	37	259.9	259.9	nozzle off.		
Same three sections of hose laid straight; water supplied by rotary fire pump at higher pressure.																	
August 31—P.M	2	55	85	74	32	+0.10	+0.10	106.76	77.29	171.8	17.15	94	201.5	201.5	¾	smooth	(b)
"	2	07	.....	74	33	"	"	61.38	24.16	170.2	21.87	44	230.1	230.1	1¼	"	(h)
"	1	56	.....	74	34	"	"	72.83	28.71	170.2	25.92	52	250.2	250.2	1¼	"	(h)
"	1	45	.....	74	35	"	"	93.92	37.09	170.2	33.39	67	284.3	284.3	1¼	"	(h)
"	1	36	.....	74	36	"	"	102.73	40.62	170.3	36.47	73	297.9	297.9	1¼	"	(h)
Same three sections, with three additional ones, all laid straight; average diameter of the six sections = 2.54 inches; water from City Reservoir.																	
September 4—A.M	9	54	65	71	37	+0.05	+0.10	67.04	29.82	338.3	11.00	50	160.6	160.7	1	smooth	(c)
"	9	44	.....	71	38	"	"	66.00	21.89	"	13.04	46	175.8	175.9	1¼	"	(A)
"	9	28	.....	71	39	"	"	65.29	16.19	"	14.51	42	186.0	186.1	1¼	"	(h)
Same hose as last experiments, but gauges connected at 50 feet from ends, thus including four sections (average diameter, 2.54). Bourdon gauges used in the two following experiments and placed close to hose. Hose all laid straight; water from City Reservoir. .																	
September 3—P.M	5	35	66	71	40	00	+0.10	61.6	36.2	227.3	11.17	50	162.0	162.1	1	smooth	(c)
Same as Experiment No. 40, except that hose was left lying with the natural sinuosity due to its elongating when pressure was turned on; this line contained about 25 bends between gauges; average radius 5 to 8 feet; length of curves about 60 degrees of arc; no kinks or cramps.																	
September 3—P.M	5	23	66	71	41	00	+0.10	61.8	35.5	227.3	11.57	50	160.8	160.9	1	smooth	(c)
Same kind of hose between gauges; down-str. gauge 50 ft. up from nozzle; up-str. gauge 25 ft. from hydrant as usual. Diam. prob. abt. 2.53.																	
August 30—A.M	11	38	90	72	42	+0.20	0.0	61.31	40.73	112.8	18.26	53	208.5	208.5	1¼	smooth	(A)
"	1	39	.....	72	43	"	0.0	63.17	41.95	112.8	18.81	54	211.9	211.9	1¼	"	(A)
"	11	54	.....	72	44	"	0.0	61.67	36.58	111.6	22.48	51	229.4	229.4	1¼	"	(h)

Per cent. increased loss of pressure due sinuosity.

5.0

TABLE No. 5—(*Continued*).—EXPERIMENTS ON FRICTION LOSS IN FIRE HOSE.

DATE.—1888.	Time. H. M.	Temperature, Fahr. Air (approx.)	Temperature, Fahr. Water.	No. of Experiment.	Pressure Gauge, Corrections, due Level, etc., Used. Up Stream.	Pressure Gauge, Corrections, due Level, etc., Used. Down Stream.	Observed Pressures at Piezometers (Corrected). Up Stream.	Observed Pressures at Piezometers (Corrected). Down Stream.	Length of Hose between Piezometers.	Loss of Pressure per 100 feet in Length of Hose.	Average Pressure in Hose.	Actual Discharge of Nozzle as Measured in Tank.	Mean Quantity Flowing through Hose, Corrected for Leaks.	Nozzle Used. Size.	Nozzle Used. Kind.
Sample D: 2½-inch Woven Cotton, Rubber Lined Hose, with very smooth interior. (Boston Woven Hose Co.'s "O. K" Brand.) (A medium weight unjacketed hose.) Av. diam. measd. in Expt. No. 46, 2 49 inches. Three 50-foot sections laid straight and supplied from City Reservoir.															
September 28	3 41	60	62	45	+0.02	−0.12	64.11	46.32	170.1	10.46	57	200.1	200.1	1	smooth (*c*)
" 28	3 51	.....	.....	46	"	"	61.34	38.07	170.3	13.66	51	233.1	233.1	1¼	" (*A*)
" 29	9 28	.....	60	47	"	"	58.63	30.36	170.5	16.58	46	257.0	257.0	1¼	" (*h*)
" 28	4 42	.....	62	48	"	"	59.03	30.55	170.3	16.72	46	258.8	258.8	1¼	" (*h*)
" 28	4 48	.....	62	49	"	"	56.98	24.22	170.5	19.21	42	277.8	277.8	1¾	" (*f*)
" 29	9 56	.....	60	50	"	"	56.71	24.04	171.6	19.04	42	278.6	278.6	1¾	" (*f*)
One section from the above—laid straight—average diameter 2.49 inches. Up-stream Piezometer, 50 feet from Hy. Down-stream piezometer, 50 feet from nozzle. Mer. gauges set side by side midway of hose, with long tubes leading thence to piezometers.															
September 24	2 18	60	63	51	00	00	63.76	54.10	57.20	16.89	59	259 6	259.6	1½	smooth (*A*)
"	6 14	.....	63	52	00	00	63.86	54.13	57.82	17.01	59	259.5	259.5	1½	" (*A*)
"	2 29	.....	63	53	00	00	58.47	43.85	57.17	25.57	51	324.3	324.3	1¾	" (*f*)
"	6 36	.....	63	53½	00	00	58.63	43.86	57.82	25.54	51	325.0	325.0	1¾	" (*f*)
A comparison of Experiments 51 and 52 with Experiments 47 and 48 is interesting as showing rate of loss of pressure to be same whether length is 50 or 150 feet.															
Sample C: 2½-inch woven cotton rubber-lined hose, with very smooth interior, Boston Woven Hose Co.'s "Boston Fire Jacket" Brand. This was intended to be the same as Sample D, except that a jacket was woven about its exterior. Mean diameter, measured in Experiment 55 = 2.47 inches. Three 50-foot sections laid straight and supplied from City Reservoir.															
August 28	2 18	68	71	54	+0 36	+0.16	64.17	46.98	162.	10.61	57	202.5	202.6	1	smooth (*c*)
"	2 30	.....	71	55	"	"	61.45	38.69	161.6	14.08	52	234.9	234.9	1¼	" (*A*)
"	2 41	.....	71	56	"	"	59.18	31.18	161.5	17.34	47	261.	261.	1¼	" (*h*)
"	2 58	.....	71	57	"	"	56.08	24.29	161.3	19.71	42	278.2	278.2	1¾	" (*f*)
"	3 10	.....	71	58	+0.43	+0.23	54.64	16.54	161.3	23.62	37	308.	308.	nozzle off.	
Sample C': A second sample of hose, intended to be precisely like C. Same brand. Mean diameter, measured in Experiment 60 = 2.47 inches. Three 50-foot sections laid straight and supplied from Reservoir.															
September 29	11 23	55	60	59	+0.02	−0.12	64.15	46.45	154.6	11.45	57	200.8	200.8	1	smooth (*c*)
"	11 28	.....	.....	60	"	"	61.49	38.18	"	15.08	55	233.4	233.4	1¼	" (*A*)
"	11 56	.....	.....	61	"	"	59.11	30.59	"	18.45	46	257.3	257.3	1¼	" (*h*)
"	12 03	.....	.....	62	"	"	57.12	24.18	"	21.31	37	279.2	279.2	1¾	" (*f*)
(The above observation shows loss in C' to be about 5 per cent. greater than in C—no special reason for this is evident. Perhaps there was some difference in character of surface, located where it could not be observed.)															

NOTE—C and C' are omitted from plotting on Fig. 48 to avoid confusion. On original the curve for C agrees very closely with the curve for Sample D.

TABLE No. 5—(*Continued*).—EXPERIMENTS ON FRICTION LOSS IN FIRE HOSE.

DATE.—1888.	Time. H. M.	Temperature, Fahr. Air (Approx.)	Temperature, Fahr. Water.	No. of Experiment.	Pressure Gauge, Corrections, due Level, etc., Used. Up Stream.	Pressure Gauge, Corrections, due Level, etc., Used. Down Stream.	Observed Pressures at Piezometers (Corrected). Up Stream.	Observed Pressures at Piezometers (Corrected). Down Stream.	Length of Hose between Piezometers.	Loss of Pressure per 100 feet in Length of Hose.	Average Pressure in Hose.	Actual Discharge of Nozzle as Measured in Tank.	Mean Quantity Flowing through Hose, Corrected for Leaks.	Nozzle Used. Size.	Nozzle Used. Kind.
Sample H: 2½-inch Knit Cotton Rubber Lined Hose. (The Cornelius Callahan Co.'s "Mill" Brand.) Three 50-foot sections laid straight and supplied by City Reservoir. Mean diameter, 2.62 inches. Measured under conditions of Experiment No. 64.															
August 28	4 33	68	71	63	+0.36	+0.16	64.10	47.51	157.1	10.56	57	203.	203.	1	smooth (c)
"	4 18	.....	71	64	"	"	61.56	39.50	157.6	14.00	52	236.7	236.7	1¼	" (A)
"	4 42	.....	71	65	"	"	59.06	31.83	157.3	17.31	47	264.5	264.5	1¼	" (h)
"	4 51	.....	71	66	"	"	56.92	25.30	"	20.10	43	284.3	284.3	1⅜	" (f)
"	4 59	.....	71	67	"	+0.23	54.35	16.87	"	23.83	37	310.8	310.8		nozzle off.
Same three sections laid straight, but supplied by rotary pump under higher pressure.															
August 31	3 45	85	74	68	+0.10	+0.10	100.26	83.44	158.4	10.61	93	208.8	208.8	⅞	smooth (b)
"	3 33	.....	74	69	"	"	55.86	29.92	158.6	16 36	44	256.9	256.9	1¼	" (h)
"	3 24	.....	74	70	"	"	74.54	40.44	"	21.50	59	297.2	297.2	1¼	" (h)
"	3 17	.....	74	71	"	"	90.66	49.32	"	26.07	72	328.	328.	1¼	" (h)
Six sections, including the above three—laid straight and supplied from Reservoir. Mean diameter, 264 inches. Measured under conditions of Experiment 73.															
September 4	4 25	65	71	72	+0.10	+0.10	65.57	40.03	316.6	8.07	54	186.3	186.4	1	smooth (c)
"	4 35	.....	71	73	"	"	63.64	31.21	"	10.24	48	209.7	209.8	1¼	" (A)
"	4 45	....	71	74	"	"	61.90	23.90	"	12.00	44	227.3	227.4	1¼	" (h)
"	4 13	.....	.....	75	"	"	65.72	39.94	"	8.14	54	185.8	185.9	1	" (c)
In Experiment 75 the same sections of hose used in Experiments 72-74 was used, but was left lying with the natural sinuosity due to its elongation of 10 feet, under pressure—it having been straightened prior to admitting the water. Fig. 50 is from a photograph taken during this Experiment. There were about twenty-five curves; average radius was probably 6 or 8 feet. Experiment 75 shows this sinuosity to have increased the friction loss only 2 per cent., an amount almost inappreciable under conditions of this experiment. Take note, however, that this brand of hose elongates less than some others.															
Sample I—Hose similar to last sample, but a little heavier grade. (The Cornelius Callahan Co.'s "Volunteer" Brand.)															
August 28	5 36	60	71	76	+0.36	+0.16	64.11	48.32	157.4	10.03	58	205.5	205.5	1	smooth (c)
"	5 45	.....	71	77	"	"	61.27	40.26	"	13.35	52	238.8	238.8	1¼	" (A)
"	5 55	.....	71	78	"	"	58.75	32.68	157.1	16.59	47	267.2	267.2	1¼	" (h)
"	6 02	.....	71	79	"	"	56.43	26.20	"	19.24	43	289.9	289.9	1⅜	" (f)
"	6 08	.....	71	80	"	"	53.46	17.57	157.0	22.86	37	318.6	318.6		nozzle off.

TABLE No. 5—(*Continued*).—EXPERIMENTS ON FRICTION LOSS IN FIRE HOSE.

DATE.—1888.	Time. H.	Time. M.	Temperature, Fahr. Air (approx.)	Temperature, Fahr. Water.	No. of Experiment.	Pressure Gauge, Corrections, due Level, etc., Used. Up Stream.	Pressure Gauge, Corrections, due Level, etc., Used. Down Stream.	Observed Pressures at Piezometers (Corrected). Up Stream.	Observed Pressures at Piezometers (Corrected). Down Stream.	Length of Hose between Piezometers.	Loss of Pressure per 100 feet in Length of Hose.	Average Pressure in Hose.	Actual Discharge of Nozzle as Measured in Tank.	Mean Quantity Flowing through Hose, Corrected for Leaks.	Nozzle Used. Size.	Nozzle Used. Kind.
SAMPLE B.																
August 29	8	40	61	70	100	+0.36	+0.16	63.76	50.14	154.6	8.80	59	209.0	209.0	1	smooth (*c*)
"	9	02	.....	70	101	"	"	60.64	42.10	154.5	12.00	53	245.2	245.2	1 1/16	" (*A*)
"	9	15	.....	70	102	"	"	56.53	33.75	"	14.74	47	271.6	271.6	1 1/16	" (*h*)
"	9	21	.....	70	103	"	"	55.58	27.89	"	17.92	43	300.2	300.2	1 1/16	" (*f*)
Six sections of hose used in the three following experiments—*i. e.*, the same hose used in Experiments 100–103, with as much more added.																
September 5	9	13	75	70	104	+0.05	+0.10	64.48	42.18	309.3	7.21	54	191.9	192.	1	smooth (*c*)
"	9	22	.....	70	105	"	"	62.69	33.69	"	9.38	49	218.7	218.8	1 1/16	" (*A*)
"	9	40	.....	70	106	"	"	60.99	26.23	"	11.24	45	239.4	239.5	1 1/16	" (*h*)
SAMPLE A.																
August 29	10	50	64	70	107	+0.36	+0.16	63.29	51.32	153.1	7.81	59	211.9	211.9	1	smooth (*c*)
"	11	14	.....	70	108	"	"	57.04	35.96	152.9	13.79	48	280.8	280.8	1 1/16	" (*h*)
"	11	21	.....	70	109	"	"	54.67	29.39	"	16.53	44	308.	308.	1 1/16	" (*f*)
"	11	26	.....	70	110	"	"	51.16	19.99	"	20.39	37	339.9	339.9	nozzle off	
One section from the above (diam. av. .01 inch smaller than mean of the three above) tested with apparatus differently arranged. (Cor. made for diff. in diam.																
September 25	4	47	60	63	110½	0.	0.	.....	.....	51.8	16.34	56	305.4	305.4		
SAMPLE J.																
August 30	8	38	90	72	111	+0.36	+0.16	64.00	55.19	102.2	8.62	61	199.7	202.1	1	smooth (*c*)
"	9	04	.....	72	112	"	"	61.55	49.87	"	11.43	57	230.1	232.3	1 1/16	" (*A*)
"	9	33	.....	72	113	"	"	59.44	45.14	"	13.99	54	255.6	257.6	1 1/16	" (*h*)
"	10	20	.....	72	114	"	"	56.54	40.45	"	15.74	50	272.5	274.2	1 1/16	" (*f*)
"	10	38	.....	72	115	"	"	54.91	35.81	102.3	18.67	47	297.4	298.8	nozzle off	
SAMPLE M.																
September 10	4	40	75	70	116	−0.20	+0.10	62.57	45.95	106.2	15.66	56	156.5	156.5	7/8	smooth (*b*)
"	5	10	.....	70	117	"	"	59.63	37.45	"	20.32	50	181.5	181.5	1	" (*c*)
"	5	27	.....	70	118	"	"	55.49	28.59	"	25.32	44	205.9	205.9	1 1/16	" (*A*)
"	5	36	.....	70	119	"	"	50.97	20.67	"	28.53	37	219.9	219.9	1 1/16	" (*h*)
"	5	42	.....	70	120	"	"	50.61	15.85	"	32.73	35	236.7	236.7	1 1/16	" (*f*)
SAMPLE N.																
August 24	.....	.....	70	72	121	.....	.....	65.17	28.48	153.	23.98	.....	157.1	163.	1	smooth (*c*)
"	.....	.....	.....	72	122	.....	.....	65.43	28.69	"	24.01	.....	158.3	164.	1	" (*c*)
"	.....	.....	.....	72	123	.....	.....	63.22	13.16	"	32.72	.....	188.4	194.	1,319	noz. off
"	.....	.....	.....	72	124	.....	.....	63.38	13.20	"	32.80	.....	188.2	194.	"	" "

TABLE No. 5—(*Continued*).—EXPERIMENTS ON FRICTION LOSS IN FIRE HOSE. Following samples were tested by water from City Reservoir. Diameter was in all cases measured during experiment with water discharging from 1⅛-inch nozzle, under full reservoir pressure. Length of hose between piezometers was also measured under pressure, and includes the elongation due pressure. Hose was in each case straightened before beginning observations, except as noted for Sample E in Experiments 92, 93, 94. For fuller description of samples see Table No. 6.

DATE.—1888.	Time. H.	Time. M.	Temperature, Fahr. Air. (approx.)	Temperature, Fahr. Water.	No. of Experiment.	Pressure Gauge, Corrections, due Level, etc. Used. Up Stream.	Pressure Gauge, Corrections, due Level, etc. Used. Down Stream.	Observed Pressures at Piezometers (Corrected). Up Stream.	Observed Pressures at Piezometers (Corrected). Down Stream.	Length of Hose between Piezometers.	Loss of Pressure per 100 feet in Length of Hose.	Average Pressure in Hose.	Actual Discharge of Nozzle as Measured in Tank.	Mean Quantity Flowing through Hose, Corrected for Leaks.	Nozzle Used. Size.	Nozzle Used. Kind.		Per cent. increased loss of pressure due sinuosity.
								SAMPLE G.										
September 3	11	42	70	72	81	+0.14	+0.10	64.15	48.28	155.7	10.19	58	204.9	204.9	1	smooth	(c)	
"	11	50	.....	72	82	"	"	61.46	40.08	155.6	13.74	52	238.6	238.6	1¼	"	(A)	
"	1	28	.....	72	83	"	"	58.87	32.48	155.3	16.99	47	266.5	266.5	1½	"	(h)	
"	1	35	.....	72	84	"	"	56.62	25.91	"	19.77	43	288.2	288.2	1⅝	"	(f)	
"	1	45	.....	72	85	"	"	53.89	17.36	"	23.52	37	314.2	314.2	nozzle off.			
								SAMPLE E.										
October 10	10	03	43	56	86	+0.20	+0.03	68.44	63.05	153.2	3.52	67	132.6	132.6	¾	cone	(a)	
"	10	16	.....	56	87	"	"	64.56	55.80	153.1	5.72	62	169.9	169.9	¾	"	(b)	
"	10	24	.....	56	88	"	"	63.48	50.49	"	8.48	59	209.2	209.2	1	"	(c)	
"	10	37	.....	56	89	"	"	60.43	42.57	"	11.67	53	244.3	244.3	1¼	"	(A)	
"	11	08	.....	56	90	"	"	57.42	35.04	153.4	14.59	48	274.6	274.6	1½	"	(h)	
"	11	16	.....	56	91	"	"	54.82	28.29	"	17.29	43	300.1	300.1	1⅝	"	(f)	
Same hose used in Experiments 86 to 91, but with natural sinuosity due elongation under pressure.																		
October 10	2	59	42	56	92	+0.20	+0.03	43.63	30.12	153.3	8.81	38	204.0	204.0	1 $\frac{3}{16}$	ring	(l)	8.2
"	2	50	.....	56	93	"	"	57.64	40.16	"	11.40	50	236.1	236.1	1 $\frac{3}{16}$	"	(l)	4.4
"	3	09	.....	56	94	"	"	58.13	39.99	"	11.83	51	238.7	238.7	1⅛	smooth	(B)	6.0
Amount of sinuosity probably not very different from Experiment 75, though somewhat greater. A photograph with plate horizontal, showing this sinuosity, was taken from roof of adjacent high mill, but was accidentally destroyed.																		
								SAMPLE F.										
October 15	3	52	50	54	95	00	00	66.13	61.19	51.7	9.56	65	177.7	177.7	¾	cone	(b)	
"	4	06	.....	54	96	00	00	63.45	56.12	51.8	14.15	61	220.8	220.8	1	"	(c)	
"	4	13	.....	54	97	00	00	59.94	49.52	51.7	20.15	56	263.7	263.7	1¼	"	(A)	
"	4	27	.....	54	98	00	00	56.25	42.57	51.6	26.51	51	304.1	304.1	1½	"	(h)	
"	4	33	.....	54	99	00	00	52.76	35.87	51.6	32.73	46	336.2	336.2	1⅝	"	(f)	

INFLUENCE OF SMOOTHNESS OF SURFACE OF WATERWAY UPON LOSS OF PRESSURE IN HOSE.

The most interesting and valuable point illustrated by the above table is the great effect which the smoothness of inside of hose exerts on the amount of pressure lost by friction. (See next page and also Fig. 47.)

Compare Sample *K* with Sample *D*. Each was a hose of woven cotton fabric of medium weight, lined with rubber, and both were made by the same manufacturer, and were practically alike, with the exception that *K* was rough inside, while *D* was smooth.

Sample *K* was made as most "mill hose" and much fire department hose is ordinarily made, viz., with a rather thin rubber lining, which was in calendering permanently roughened by the twill of the cloth used, and which is further roughened and corrugated by its conformation to the threads of the fabric, and is still further corrugated when in use by the rubber lining being forced by the water pressure into the vacant crevices between the threads; thus giving a surface as shown by the photograph in Fig. 47.

Sample *D* was made of same material, but with more care. Its rubber lining was calendered smoothly, and was slightly thicker than that in Sample *K*, and means were adopted for filling the crevices between the threads so that the rubber lining should be well backed up, and its inner surface not forced into a corrugated form by the action of the water pressure. This filling of the crevices may be attained either by the free use of suitable rubber cement, or by inserting the rubber lining into the cotton fabric in a semi-plastic, partially vulcanized condition, and then completing vulcanization under such conditions as to permit the rubber before hardening, to "flow" slightly, and thus fill the crevices between the threads.

Careful weaving is also essential. Sample *E* had an excellent lining, which was comparatively free from minute ridges, but a waviness of surface was produced apparently by the unequal tension in loom; and that the friction loss in this was, for equal diameters, relatively higher than *D* was mainly due to this slight irregularity of weaving, rather than to the character of the lining.

The cost of Sample *D*, in which the friction loss was only 14.2 pounds, was only five cents per foot greater than Sample *K*, in which loss was 25.5 pounds; part of which cost was due to heavier fabric and greater thickness of rubber lining. The extra cost of obtaining the greater smooth-

TABLE No. 6.—COMPARATIVE FRICTION LOSS IN VARIOUS KINDS OF FIRE HOSE. The following comparison is made on the basis of 240 gallons per minute, flowing through hose in each case, which is about the quantity discharged by a 1⅛-inch smooth nozzle under a pressure of 40 pounds per square inch at base of play pipe.

SAMPLE OF HOSE.	Diameter of couplings. Inches.	Average **internal diameter of hose.** Inches.	Mean velocity in hose. Feet per sec.	Increase in length under 50 lbs. average pressure.	Observed **loss of pressure** due friction in each 100 ft. of hose. Hose straightened and length measured under pressure. Lbs. per sq. in.	Percentage corresponding to diam. of hose to be added or subtracted to give friction which would have existed had diam. been exactly 2½ inches.	**Loss of pressure** due friction in each 100 ft. of hose, which this same hose would have shown **had diam. been exactly** 2½ inches. Lbs. per sq. in.
Sample A. **2 1-2 in. Solid Rubber Hose. Boston Woven Hose Co.'s "Extra."** A heavier hose than the next, weighing 25% more. The interior of this hose is free from ridges due threads of fabric, and was intended to be smooth as rubber could be made; being made on a highly polished steel mandrel.	2.52	**2.65**	13.96	¾%	**10.0**	**Add 34%**	**13.4**
Sample B. **2 1-2 in. Solid Rubber Hose. R. W. H. Co.'s "Volunteer."** The interior of this hose is free from ridges due threads of fabric, and very smooth, but was made on a mandrel less highly polished than the last.	2.53	**2.60**	14.50	1½%	**11.5**	**Add 22%**	**14.0**
Sample C. **2 1-2 in. Woven Cotton, Rubber-Lined. R. W. H. Co's "Boston Fire Jacket Hose."** A Regular heavy Fire Department Hose. Rubber lining is thick, and interstices between threads next to rubber lining filled with rubber, so that inner surface remains almost free of ridges under pressure. Hose of same grade as Sample D with addition of a jacket. (See Photograph.)	2.53	**2.47**	16.07	4%	**15.0**	**Deduct 6%**	**14.1**
Sample D. **2 1-2 in. Woven Cotton, Rubber-Lined. R. W. H. Co.'s "O. K. Hose."** A medium-weight unjacketed hose. Rubber lining thicker than Sample K, and interstices between threads next to lining filled with rubber, so that inner surface remains almost free of ridges under pressure. Smoothness and character of lining apparently the same as Sample C. (See Photograph.)	2.47	**2.49**	15.81	5%	**14.5**	**Deduct 2%**	**14.2**
Sample E. **2 1-2 in. Knit Cotton, Rubber-Lined. N. Y. B. & P. Co.'s "Cable No. 2 Hose."** A medium-weight hose. Inner surface medium smooth under pressure. Interstices between threads next lining well filled wth rubber. (See Photograph.)	2.50	**2.68**	13.65	3½%	**11.3**	**Add 42%**	**16.0**
Sample F. **2 1-2 in. Knit Cotton, Rubber-Lined. N. Y. B. & P. Co.'s "Dart Hose."** A cheap, light-weight hose. Interior surface medium smooth.	2.50	**2.50**	15.69	4½%	**16.8**	**0**	**16.8**
Sample G. **2 1-2 in. Knit Cotton, Rubber-Lined. Callahan's "Jacket Hose."** A regular Fire Department Hose. Said to be about the same grade as Sample I with a jacket added.	2.51	**2.60**	14.50	1¾%	**13.9**	**Add 22%**	**17.0**

Sample H. **2 1-2 in. Knit Cotton, Rubber-Lined. Callahan's "Mill Hose."** A rather cheap, light-weight hose. Inside rather rough, due conformation of rubber lining to threads of fabric.	2.51	**2.62**	14.28	3%	**14.4**	**Add 27%**	**18.3**
Sample I. **2 1-2 in. Knit Cotton Rubber-Lined. Callahan's "Volunteer Hose."** A somewhat heavier hose than the last, otherwise apparently the same. (See Photograph.)	2.51	**2.69**	13.55	2½%	**13.5**	**Add 44%**	**19.4**
Sample J. **2 1-2 in. Leather Hose. S. Eastman & Co.'s "Improved."** A leather hose of excellent construction. Laps cut square.	2.50	**2.80**	12.51	2¼%	**12.2**	**Add 76%**	**21.5**
Sample K. **2 1-2 in. Woven Cotton, Rubber-Lined. R. W. H. Co's "Mill Hose."** A cheap hose with medium-thin rubber lining, which under pressure conformed to threads of fabric, thus making interior full of small ridges. (See Photograph.) I infer from comparative appearance of roughness that most other makes of woven "Mill Hose" of same weight would as now made give similar friction, but that they can be improved as illustrated in Sample D.	2.48	**2.53**	15.31	5%	**24.1**	**Add 6%**	**25.5***
Sample L. **2 1-2 in. Unlined Linen Hose.** This was an excellent piece of hose, made by Ross & Turner, and fairly represents friction loss in all ordinary unlined linen hose. (See Photograph.)	2.50	**2.60**	14.50	2½%	**27.2**	**Add 22%**	**33.2**
Sample M. **2 in. Woven Cotton, Rubber-Lined Hose.** Smoothness apparently same as sample D, as judged by inspection of interior at ends of sample.	2.07	**2.12**	21.81	4½%	**33.2**	**Deduct 56%**	**14.6**
Sample N. **2 1-4 in. Linen Hose with 2 in. Couplings.** Fabric same as Sample L. (Value deduced from experiments with 200 gallons per minute flowing in this hose.)	1.95	**2.30**	18.53		**49.5**	**Deduct 34%**	**32.7**

For comparison with above, it may be stated that the loss of pressure due friction in a common, clean, straight wrought-iron pipe coated with tar or asphaltum, and 2½ inches diameter, discharging 240 gallons per minute would be,

computing and interpolating from experiments of Hamilton Smith, Jr., 15.7 lbs. per 100 feet
" " " " " " " Henry Darcy, 14.0 " " " " " " } mean **14.8**

The correction given in the sixth column is based upon the well-known hydraulic rule, that for the same quantity flowing in long pipes of different diameters, but equal smoothness, the friction loss is in inverse proportion to the fifth power of the diameter.

The truth of this rule within the limits of the above experiments is demonstrated very well by a comparison of the last two experiments on samples **M** and **N**, with experiments on samples **C** and **L**.

The figures in the seventh column give the true basis for judging of the relative excellence of a hose as regards smoothness of finish of interior.

*In justice to the Boston Woven Hose Co., the writer desires to state, that since learning the result of these experiments, they have been experimenting and modifying process of manufacture so that interior of mill hose shall retain a smooth surface even under heavy water pressure.

ness, when the proper arrangements are made at factory, will, it is believed, add but a very small percentage to the cost of the hose.

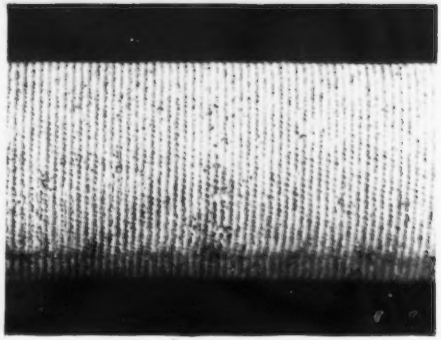
This point is well worthy the attention of all manufacturers of fire-hose. The writer is led to especially emphasize it from having many times heard hose manufacturers and hose salesmen affirm most positively that this little roughness of interior surface had no influence on the loss of pressure, that "the water next the side lay dead, etc.;" which notions, though conclusively proved to be erroneous, as every hydraulic engineer knows, by the experiments of Darcy thirty-five years ago, are still advocated as an aid to the disposal of imperfect fire-hose.

To determine the cause of the difference in friction loss in different kinds of hose, and to find out the condition of the surfaces exposed to the current of water under the practical conditions of use, plaster casts were made of the inside of pieces of hose from 1 to 3 feet in length, cut from the hose used in the experiments; to insure that these casts were fairly representative several casts from different parts of the hose were in some cases made. In making them, ordinary couplings were attached to these samples, and one end was capped. The sample was placed upright, filled with plaster of Paris, and then being instantly attached to a hydrant, a water pressure of 50 pounds per square inch was maintained on it until the plaster had set. These casts are of such interest in showing effect of roughness that photographs made from them are presented herewith. From inspecting these a reason will be seen why the friction loss in unlined linen hose is two and one-third times as great as in well made rubber lined hose, and nearly two and a half times as much as in an extra smooth solid rubber hose.*

The very great influence which smoothness of interior surface was found to exert upon the friction loss may excite question as to the accuracy of the observations. I would, therefore, call especial attention to the detailed results on Samples *L*, *K* and *D*, as given in Table No. 5.

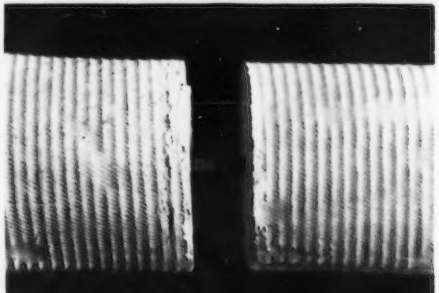
First.—That the results are very accurate, the unusual precision of the apparatus leaves almost no room for doubt. That the quantity flowing was correctly measured is proved by a comparison which has been made for most experiments between the discharge as found by measurement

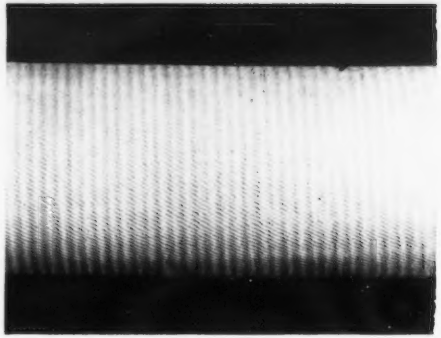
* It may be well to add, that while the great friction loss, as well as susceptibility to injury by chafing on cinders or sharp corners, makes unlined linen hose undesirable for use in long lines or for general outside use, nevertheless its extreme lightness, compactness and superior durability render it, in our opinion, better suited than any other kind for *inside* use in dry, well ventilated situations ,such as on the stairway standpipes of a mill.



SAMPLE L. **UNLINED LINEN HOSE.**

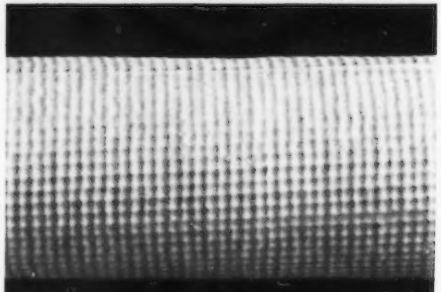
33.2 lbs. pressure lost by friction per 100 feet in length (or 2⅓ times as much loss as in sample C, shown below).





SAMPLE X. Not tested for friction. Cast taken to illustrate unnecessary roughness often caused in process of manufacture.

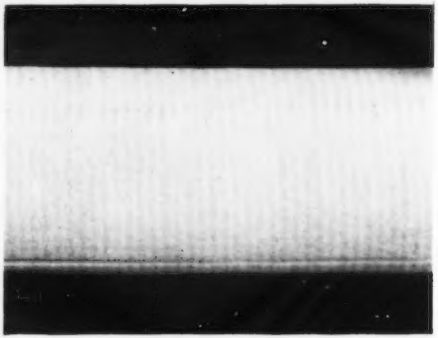
Fabric and lining same as C, except that twilled cloth was used in calendering face of rubber lining, thus roughening surface.



SAMPLE K. **WOVEN COTTON, RUBBER-LINED "MILL HOSE."**
(Average depth of corrugations, $\frac{15}{1000}$ to $\frac{27}{1000}$ inch.)

25 5 lbs. pressure by friction per 100 feet in length of hose, or 80 per cent more loss than in sample D or C, shown below.

(Rubber lining was rather thin, and crevices between threads next lining not being well filled, the water pressure caused inner surface to conform to threads of fabric.)



SAMPLE C. **WOVEN COTTON, RUBBER-LINED HOSE.**
(Average depth of corrugations, $\frac{1}{1000}$ to $\frac{8}{1000}$ inch.)

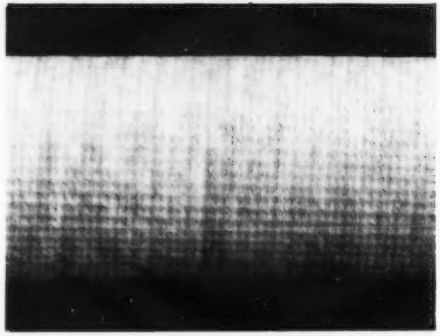
14.1 lbs. pressure lost by friction per 100 feet.

Rubber lining slightly thicker than in sample K, and interstices between threads next lining well filled with rubber, so inner surface remained smooth under pressure.

SAMPLE D had same kind of rubber lining, and gave loss of 14.2 lbs. per 100 feet.

SAMPLE I. **KNIT COTTON, RUBBER-LINED HOSE.**
Interstices between threads next lining not well filled.
Average height of round-about ridges, about $\frac{1}{100}$ inch.
Average height of ridges which run lengthwise, about $\frac{15}{1000}$ inch.

19.4 lbs. pressure lost by friction per 100 feet in length (or 37 per cent more friction lost than in sample C).



SAMPLE E. **KNIT COTTON, RUBBER-LINED HOSE.**
Interstices between threads next lining well filled.

16.0 lbs. pressure lost by friction per 100 feet in length (or 13 per cent more friction loss than in Sample C).

FIG. 47. PHOTOGRAPHS FROM PLASTER CASTS OF INTERIOR OF FIRE HOSE.

Casts were all taken under a pressure of 50 lbs. per square inch. Photographs are half size of originals.

Losses of pressure given below are those found for 240 gallons per minute (or a good $1\frac{1}{8}$ inch fire stream) flowing in hose exactly $2\frac{1}{2}$ inches in diameter.

in the tank and the discharge computed for the given nozzle under the known pressure at its base.

Second.—That the piezometers were not subject to local influences is proved by the same result being obtained when positions of piezometers were changed by moving them 50 feet up-stream or down-stream in the same line of hose.

Third.—That there was no local obstruction in hose is proved by obtaining the same result with different pieces used.

Fourth.—That results are not influenced by accidental or occasional errors is shown by the regular, nearly geometrical form of the curve, and it is fair to add that throughout the whole range of these experiments no observation has been excluded simply because it failed to fall into line.

Fifth.—That gauges were all right is indicated by a similar result being obtained when Bourdon test gauges were used.

Sixth.—That diameter was correctly determined within narrow limits was proved by repeating measurements independently, and also by measurements made upon the plaster casts.

Seventh.—That the value for linen hose is fairly representative is shown by results with Sample *N* as compared with *L*, and also by equally accurate experiments on another sample, which agree closely but are omitted to save space, and also by some experiments with less perfect apparatus made a year previous. And that the comparative values for linen hose are about right was shown by laying two 300-feet lines of hose, one like Sample *L*, the other rubber lined, both fed from the same hydrant and connected to similar nozzles placed side by side as in Fig. 54, and noting the difference in height attained by the jets.

Should it be remarked that differences in friction loss due to smoothness are relatively as great or greater than Darcy's experiments showed for clean pipes *vs.* those obstructed by deposits, it may be said that Darcy gives little or no means of judging of the degree of roughness of his pipes with deposits, and probably their roughness was by no means so great as would be produced by the tubercles ordinarily known as such to American engineers.

Influence of Diameter upon Loss of Pressure in Hose.

The influence of a slight difference in diameter of hose upon the loss of pressure incident to forcing a given number of gallons per minute through it, is far greater than is generally appreciated. The magnitude

of the corrections to offset variation in diameter given in column 5 of Table No. 6 will very likely excite comment and question. That the rule by which they are computed, when applied within the limits of these experiments (on hose of 2½-inch nominal diameter), is correct within about 1 per cent., is indicated by the experiments of Darcy and of Hamilton Smith, Jr.; and that, notwithstanding the slight constriction at hose coupling, the rule is practically correct and reliable as used in the table, is proved by the comparison of the last two experiments in the table with those on Samples *D* and *L*.

It will be seen that among the dozen pieces of "2½-inch" hose experimented upon, the actual internal diameter varied from a little less than 2⅜ to a little more than 2¾ inches diameter. Since ⅛ of an inch variation from 2½-inch diameter may cause a variation of about 25 per cent. in friction loss in hose with same number of gallons per minute flowing, it is seen how essential it is that we know the diameter accurately; and since one manufacturer can make 2¾-inch hose as well as another, if he starts with that object in view, it would be unfair to place the 2¾-inch hose of one against the 2½-inch hose of another, just because the bore of the couplings happened to be the same in the two cases, without allowing for the difference of diameter.

So far as I can learn, previous experimenters have not measured with precision and under pressure the diameter of the hose upon which they experimented, and therefore their results are devoid of much scientific value, although they have unquestionably been of much value in the rough-and-ready, practical way.

In the present case the interior diameter of each line of hose under experiment was measured in half a dozen or more places by calipering the external diameter at these places, while the 1⅛-inch nozzle was attached and the stream flowing under full city pressure. Immediately afterward the water was shut out, the hose at the points just calipered was flattened between clamps and blocks with a pressure intended to be about 25 pounds per square inch and again calipered, and the thickness of the fabric thus determined; which, being deducted from the external, gave the internal diameter. The hose diameters thus determined were verified in several cases by independent remeasurement in the same manner, and by comparison with diameters of plaster casts from the same hose. Considering the general agreement of these measurements, and the care used in making them, I conclude that the mean diam-

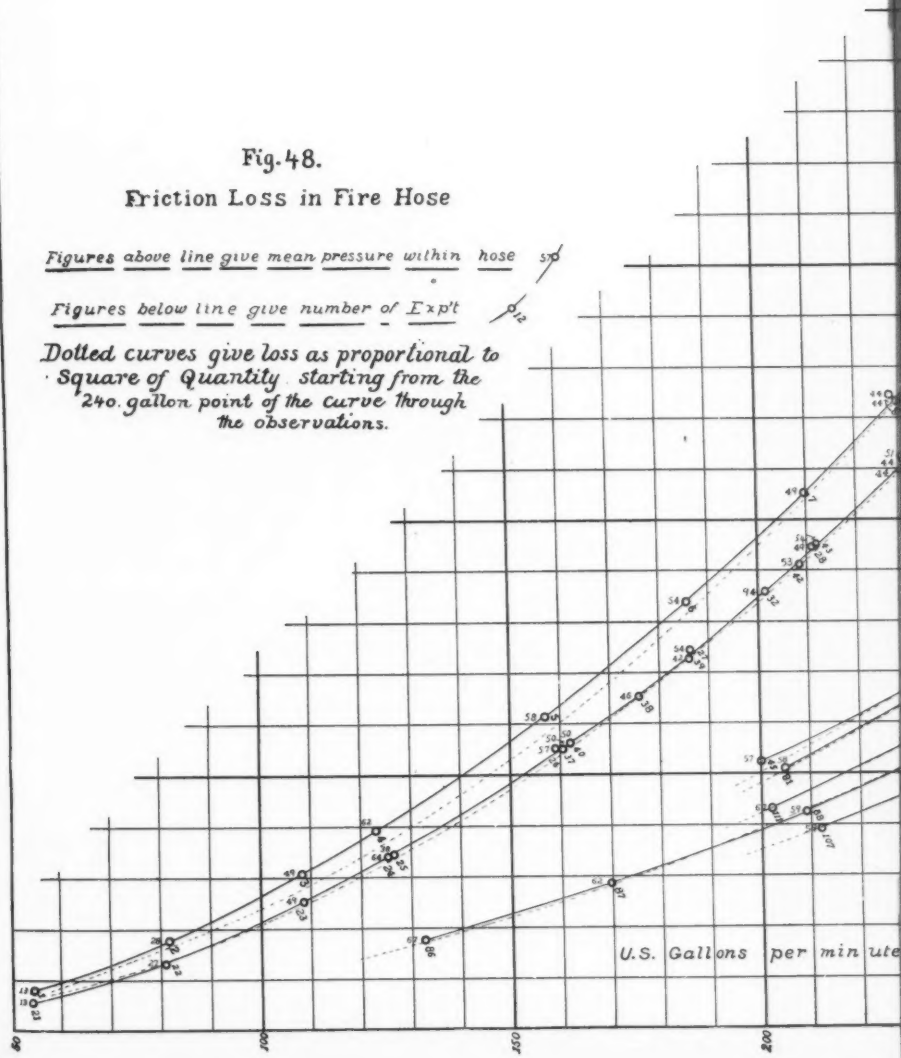
Fig. 48.

Friction Loss in Fire Hose

Figures above line give mean pressure within hose

Figures below line give number of Exp't

Dotted curves give loss as proportional to Square of Quantity starting from the 240. gallon point of the curve through the observations.



L – Unlined Linen – Diam. 2.60"
K – Rough Rubber Lined – Diam. 2.53"
D – Very Smooth Rubber Lined – Diam. 2.49"
G – Medium Rubber Lined – Diam. 2.55"
J – Leather Rubber Lined – Diam. 2.60"
E – Medium Rubber Lined – Diam. 2.80"
A – Very Smooth Solid Rubber Diam. 2.68"
Pounds pressure lost per 100 feet of hose
minute flowing through hose
250
300
350
0
10
20
30
40
50

eters as given in the table are in almost every case probably correct within 0.01 or 0.02 inch.

(An attempt was made to determine the diameter by weighing the water contained in the hose; but this method, by reason of air bubbles and of water adhering to hose, was found less satisfactory than that just described.)

Influence of Pressure on Diameter of Hose.

It might be thought that the elasticity of the hose, acting in accordance with the varying pressures of water within it, would affect seriously the rate of loss of pressure, and thus render the results of little value in indicating laws of flow in pipes under high velocities.

To determine whether or not this was the case, the following experiments were made. The ends of a line 100 feet long of each kind of hose were capped, and then the diameter measured in half a dozen places, first with a pressure of 25, then with 50, then 75, and finally 100 pounds per square inch. The hose was meanwhile free to elongate. The average amount of expansion found is given in the following table:

Effect of Pressure in Enlarging Diameter of Hose.

Kind of Hose and Maker's Name. (All Nominally 2½ inches Diameter.)	Increase of diameter corresponding to 50 pounds increase of pressure. Inches.
Sample **C**, Boston Woven Hose Co.'s woven cotton rubber-lined "Boston Fire Jacket"	0.000
Sample **L**, Ross, Turner & Co.'s woven linen hose, unlined, "Red Line"	0.005
Sample **K**, Boston Woven Hose Co.'s woven cotton rubber-lined "Mill"	0.016
Sample **G**, Cornelius Callahan Co.'s knit cotton rubber-lined "Jacket"	0.022
Sample **E**, N. Y. Belting & Packing Co.'s knit cotton rubber-lined "Cable No. 2"	0.028
Sample **B**, B. W. H. Co., solid rubber, "Volunteer"	0.030
" C. C. Co., knit cotton rubber-lined "Mill".	0.036
" **A**, B. W. H. Co., solid rubber, "Extra"	0.036
" **I**, C. C. Co., knit cotton rubber-lined "Volunteer"	0.041
Sample **J**, Samuel Eastman & Co.'s leather hose	0.054

From the expansion of diameter of hose due to an increase of pressure within it as just determined, we may readily deduce the effect that, this increase of diameter would have in decreasing frictional resistance due to flow, according to the well known law that this varies inversely as fifth power of diameter. We thus deduce that within the range of the experiments an increase of 10 pounds in mean pressure will by increasing diameter reduce the friction loss as follows:

	Per cent.		Per cent.
Sample	0.0	Sample B.....	1.2
" L.....	0.2	" H.....	1.4
" K.....	0.6	" A.....	1.4
" G.....	0.9	" I.....	1.6
" E.....	1.1	" J.....	2.2

Now let us compare these deductions with actual results of experiments upon friction loss under very different pressures, as given in Table No. 5.

Kind of Hose.	Experiments Compared.				Difference in Pressure.	Actual difference in Friction Loss by Experiment.	Loss as deduced from increase of diameter.
	No. of Experiment.	Mean Pressure.	No. of Experiment.	Mean Pressure.			
Sample L.....	11	37	12	57	20	0 per cent.	0.4 per cent.
Sample K.....	{27 / 28}	51	32	94	43	1½ "	2.6 "
Sample H.....	{63 / 64}	54	68	93	39	4½ "	5.5 "
Sample H.....	{66 / 67}	40	70	59	19	2 "	2.7 "

It may be remarked that a high pressure might possibly tend also to increase the friction loss by making the interior of a rubber hose slightly more corrugated by compressing or forcing the rubber more into the crevices between the threads, and thus offset to a greater or less extent the effect of the gain in diameter.

The agreement in the above table is, I think, very satisfactory, and not only gives confidence that the series of observations in Sample *K* and also *C* and *D* are reliable as pipe experiments under high velocities, but also shows that experiments on nearly all the other samples may be safely so used by applying a slight correction to reduce to constant diameter.

Data Furnished by these Experiments for Determining Laws of Flow in Pipes.

Let us insert here a word of explanation.

If there were now on record series of accurate experiments on flow in rigid pipes, fairly complete in their range of variation in diameter, velocity and smoothness of surface, and in which experiments but one variable had been changed at a time, thus making the result strictly determinate, I might cut this part of the discussion of these experiments very short; but, considering the unfilled gaps at present existing in our lines of data, may we not find it worth while to get all we can out of these experiments, even though they be on fire hose?

The writer believes a comparative study to show that the observations and methods of these experiments on hose as described above give results which, far as they go, equal in accuracy the pipe experiments of Darcy or other published standard experiments on flow in pipes.

Moreover, the results stated on the preceding page indicate that the flexibility and elasticity of some of these pipes do not affect the flow so as to make results essentially different from those which would be found with rigid pipes of same size and smoothness.

A feature of these experiments which might, at first sight, make them appear undesirable for this purpose, is the slight constriction at coupling; but it will be noted that for several samples this was very slight.

See also in this connection the results of experiments upon effect of bushings described a few pages farther on. These, bearing in mind that the bushings had sharp corners, while the reduction by couplings was somewhat gradual, indicate that the total effect of the existing reduction of area at coupling would increase the loss, even with sample *I*, which had the greatest difference in areas of any sample, by not more than 2 or 3 per cent.

In considering the bearing of these fire hose experiments upon the laws of flow of water in pipes, the point of special interest is:

Influence of Character of Surface upon Flow.

Reference has already been made to this and to photographs of plaster casts. But may we not here emphasize the necessity of a clear and definite description of the smoothness of the wetted surface, in order

that experiments on flow in pipes should have an exact value? Is it not useless to attempt to take a few isolated experiments upon one pipe here and another pipe there, and from such experiments to deduce the influence of velocity or diameter upon co-efficient of flow, when almost invisible differences of smoothness of surface may far outweigh these elements? Here is a good place to emphasize the fact that almost all recorded experiments upon flow in pipes of any considerable degree of roughness are rendered very vague and of little practical value because this all-important element of roughness has been so vaguely described.

Take Darcy's experiments; we often hear it stated that he found that in pipes covered with deposits the loss of head was double that in smooth pipes. How great was the roughness of these deposits? Were they as big as heads of steam boiler rivets like the tubercles which we often find in water pipes in New England cities, or were they of the size of grains of wheat? How can we apply such data in any but the most vague manner until we have such facts clearly stated?

Another point of interest is the

Influence of High as Compared with that of Moderate Velocities upon Co-efficient of Flow.

We will preface this with the remark that the question just now under discussion may, perhaps, be more clearly stated thus:

For a given pipe, does the loss of head vary in exact proportion to the square of the quantity flowing?

The answer may also be had in simple form by reference to Fig. 48. The full lines show the experimental result, the dotted lines are geometrical curves with head varying as the square of quantity and passing through the 240-gallon point of experimental curve. It is seen that the head does vary very nearly as the square of velocity; but that there is a divergence from the law, which, though small, is clearly defined for each of the curves. For *A*, *E*, *G* and *J* the divergence of the curves would be in more marked agreement with those for *L*, *K* and *D*, if the slight corrections for expansion of those samples of hose by pressure had been applied to the results before plotting.

In making the more complete comparisons we will use the well known Chezy formula as a basis. I think Fig. 47 illustrates sufficiently well that even slight differences in smoothness of surface, which are in most cases hidden from observation, may easily offset the refinements of

more complicated formulas, and for readily comparing the results with other experiments on flow in pipes, we will follow the line of investigation given in Hamilton Smith, Jr.'s "Hydraulics," edition 1886, page 213 *et seq.*, because of the complete and convenient collection of data included in his work; a collection admirable for the care with which questionable experiments have been excluded.

We compute the following from the data furnished by the experiments as detailed in Tables Nos. 5 and 6; taking off values for quantity and friction loss from a large scale plotting of the data just mentioned, similar to Fig. 48. For those kinds of hose in which loss was shown by experiments detailed on page 353, to be appreciably affected by expansion (viz., all samples except *C*, *D* and *L*), a slight correction (in no case greater than 2.4 per cent.) has been applied as per deductions of page 354. The results are shown graphically in Fig. 49.

TABLE No. 7.

VALUE OF CO-EFFICIENT n IN FORMULA $v = n\,(rs)^{\frac{1}{2}}$ FOUND TO EXIST IN FIRE HOSE OF VARIOUS DEGREES OF ROUGHNESS AND FOR VARIOUS HIGH VELOCITIES.

Chezy formula $v = n\,(rs)^{\frac{1}{2}}$ $\therefore n = \dfrac{v}{\sqrt{rs}}$

v = Mean velocity in feet per second.
n = Co-efficient for mean velocity of flow.
r = Hydraulic mean radius = ¼ diameter in feet.
s = Natural sine of hydraulic gradient.

See Fig. 49.

Sample or kind of Hose.	Diameter of Hose. Inches.	Gallons per Minute Flowing.	Pounds Lost per 100 feet per Plotted Curve.	Correction for Expansion of Hose by Pressure.	Pounds Lost per 100 feet. Corrected for Expansion.	s.	Mean Velocity in Hose. Feet per Second.	n.
				Per cent.				
A.	2.65	214.9	8.00	+0.8	8.06	.1863	12.50	123.3
	"	240.	10.00	0	10.00	.2311	13.96	123.6
	"	292.2	14.89	−1.1	14.73	.3404	17.00	124.
	"	343.8	20.90	−2.4	20.40	.4714	20.00	124.0
C.	2.47	200.1	10.66	0	10.66	.2464	13.40	119.1
	"	240.	15.00	0	15.00	.3467	16.07	120.4
	"	298.7	22.8	0	22.80	.5269	20.00	121.5
D.	2.49	200.3	10.50	0	10.50	.2427	13.20	117.7
	"	240.	14.50	0	14.50	.3351	15.81	120.
	"	288.4	20.48	0	20.48	.4733	19.00	121.3
	"	318.7	24.70	0	24.70	.5708	21.00	122.1
E.	2.68	131.9	3.45	+1.5	3.50	.0809	7.50	111.6
	"	175.8	6.17	+1.	6.23	.1440	10.00	111.6
	"	240.	11.3	0	11.3	.2611	13.65	112.3
	"	298.9	17.20	−1.1	17.01	.3931	17.00	114.8
I.	2.69	203.7	10.10	+1.	10.20	.2357	11.50	100.1
	"	240.	13.50	0	13.50	.3120	13.55	101.7
	"	283.4	19.11	−0.8	18.96	.4382	16.00	102.2
	"	318.9	22.90	−2.4	22.35	.5165	18.00	105.8
M.	2.12	154.0	14.80	+0.8	14.92	.3448	14.00	113.4
	"	187.0	21.07	+0.6	21.19	.4897	17.00	114.8
	"	240.0	33.20	0	33.20	.7673	21.81	118.4
K.	2.53	54.8	1.11	+1.6	1.13	.0261	3.50	94.3
	"	78.4	2.50	+0.8	2.52	.0582	5.00	90.3
	"	117.5	5.99	0	5.99	.1384	7.50	87.8
	"	156.7	10.55	+0.5	10.60	.2450	10.00	88.0
	"	188.0	14.91	−0.6	14.82	.3425	12.00	89.3
	"	240.	24.10	0	24.10	.5570	15.31	89.3
	"	266.4	29.38	−0.6	29.20	.6748	17.00	90.1
	"	297.7	36.42	−1.8	35.76	.8264	19.00	91.0
L.	2.60	57.9	1.79	0	1.79	.0414	3.50	73.9
	"	82.7	3.63	0	3.63	.0839	5 00	74.1
	"	124.1	7.99	0	7.99	.1846	7.50	74.9
	"	165.5	13.50	0	13.50	.3120	10.00	76.9
	"	240.	27.20	0	27.20	.6286	14.50	78.5
	"	281.3	37.03	0	37.03	.8558	17.00	78.9
	"	331.0	50.30	0	50.30	1.1624	20.00	79.6

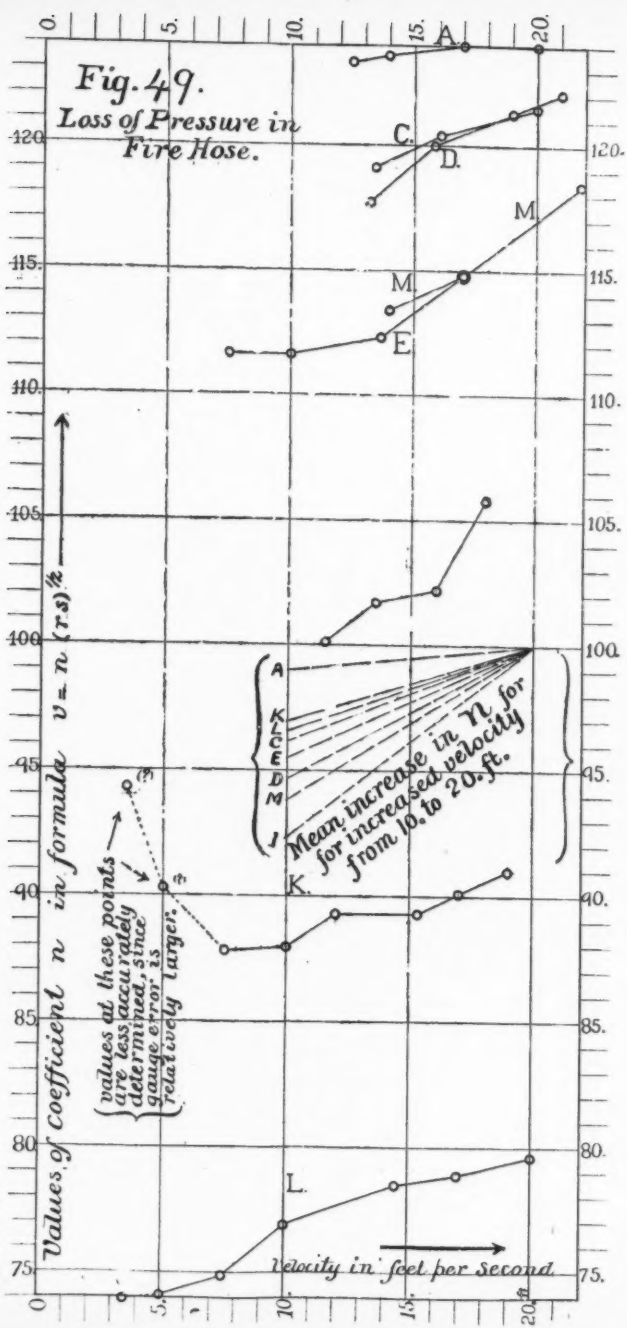


Fig. 49.
Loss of Pressure in Fire Hose.
Values of coefficient n in formula v = n (rs)½
Velocity in feet per second.
Mean increase in n for increased velocity from 10. to 20. ft.
values at these points are less accurately determined, since gauge error is relatively larger.
A
C.
D.
M.
M.
E.
K.
L.
0.
5.
10.
15.
20.
120.
115.
110.
105.
100.
95.
90.
85.
80.
75.

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The question may be asked, How do results obtained by previous experimenters on friction loss in hose agree with those just described? So far as I know, the only published results on friction loss in fire-hose making pretension to scientific accuracy are those of G. A. Ellis, previously referred to, and those of E. B. Weston. There are records of a few rough experiments in Fanning's "Water Supply Engineering," page 519, but the effect of hose friction is so influenced by several other losses of pressure as to be indeterminate. The Ellis tables have already been shown (see pages 327 and 334) to estimate discharge so wrongly as to make the figures for friction loss of very doubtful value, and, moreover, no statements are given, either of the actual diameter, or as to whether the so-called "rubber hose" was cotton fabric hose with a thin rubber lining, or was "solid rubber hose." Mr. Weston's experiments were evidently much more accurate than those of Ellis. Mr. Weston informs me that he experimented upon only a single kind of hose, namely, the so-called "solid rubber" hose, and so far as I could judge from appearance of some specimens cut from it, the character of the interior was not very different from my Sample *B*. He cut several rings from some of the hose experimented upon, and found their diameter, when not stretched by pressure, to average 2.50 inches. Lack of agreement in the results which he found with different lengths of hose indicates that the different sections used differed in diameter or surface, and it is very likely that the hose was expanded to a slightly larger diameter by the water pressure when in use than existed when diameter was measured. His hose couplings were of but 2½ inches diameter. However, the comparison stands as follows, for 240 gallons per minute flowing:

Deducing the friction loss from those experiments of Mr. Weston in which the flow was nearest to 240 gallons per minute, namely, the experiments which he numbers 11 and 22.

PRESSURE LOST BY FRICTION PER 100 FEET IN LENGTH.

	Pounds.
Per Weston's experiments on piece 96 feet long	18.3
" " " " 385 " "	14.9
Average value	16.6
Per Freeman's experiments on Sample B reduced to 2½-inch diam.	14.0
Difference	2.0

One-half pound of the above difference may be attributed to the reduction of area in the 2½-inch coupling used by Mr. Weston.

FIG. 50.

The plate (Fig. 50) shows the site of experiments upon friction loss in hose. This view illustrates sinuosity caused by elongation of hose under pressure.

In the ordinary experiments hose was carefully straightened out after admitting pressure.

Effect of Sinuosity upon Friction Loss.

The experiments on this subject were less complete than desirable, but serve the practical purpose of showing that ordinary sinuosity does not very materially interfere with flow. Almost every kind of fire-hose elongates to a greater or less degree when subjected to water pressure. The amount of this elongation for the several kinds under experiment was determined at the same time as the expansibility (see page 353); and was also repeatedly determined in the course of the experiments on friction loss by laying the empty hose in a straight line previous to the experiment and taking its length, then, after turning on the water pressure and straightening out the sinuosity produced by the stretching, its length was again measured. The mean values for the stretch or elongation of the various kinds of hose are given in Table No. 6.

The natural result of this elongation is, that though a line of empty hose be laid perfectly straight, it will become very sinuous as soon as the water is admitted. This is illustrated in Fig. 50. To determine the effect of this natural sinuosity upon the flow, an experiment upon the friction loss was made while the hose was lying as shown in Fig. 50, and immediately afterward the hose was straightened with much care to conform to a straight line previously run out by the aid of a transit and marked on the platform by a stripe of white paint.

From data given in Tables 5 and 6 we obtain the following results:

Kind of Hose.	Per cent. of elongation of hose due to 50 pounds increase of pressure.	Mean of average pressure for whole length of hose during the experiments.	No. of experiments.	Gallons per Minute flowing in hose.	Mean Velocity in hose.	Ratio of Increased loss per hundred feet, due Sinuosity to head due Velocity.	Per cent. increased loss of head with Sinuosity over loss with hose straight.	Increased loss for flow of 240 gallons per minute. Pounds per 100 feet.
	Per cent.			From To Mean.			Per cent.	
Sample L..	2½	52	4	120—224—178	10.7	1.3	6.2	1.7
" K..	2	50	1	— — 161	10.3	0.8	5	1.2
" H..	2	54	1	— — 186	11.0	0.2	2	.3
" E..	3½	46	3	204—339—226	12.9	0.6	6.2	.7
" D*.	.....	.....	..	.....	17.0	0.9	8	.8
" A*.	... .	.....	..	.....	17.7	0.7	8	1.1

Average 1.0

* The values for these two samples are deduced from the curve experiments on curve *Z* described on the three following pages.

The above justifies us in saying, in a rough and ready way, that for fire hose in general the friction loss in hose laid in its ordinary sinuous course, but not cramped or kinked, will be somewhere about 6 per cent. greater than if laid perfectly straight. Or stated in another form, that for the standard 240 gallon stream, this sinuosity will add about 1.0 pound to the loss in the hose per 100 feet.

EXPERIMENTS ON EFFECT OF CIRCULAR CURVES OF FROM 2 TO 4 FT. RADIUS.

It was thought that, by reason of flexibility of hose, some interesting information relative to general effect under high velocities of bends of large radius could be obtained; but although the experiment was made with such precautions as would seem to prevent possibility of serious error, the results are not conclusive in determining any law of general application. They are, however, deemed worth putting on record.

A set of experiments was made on September 6th with 2½-inch hose, Sample H, but as the results were unsatisfactory, another set of experiments was tried on September 24th, this time selecting hose from Sample D, on account of its uniformity of diameter at couplings, lack of change in diameter under varying pressures, and general excellence of finish. The section of hose used measured 57.2 feet in length under pressure of 59 pounds, and the piezometer couplings (See Fig. 2) were attached directly to its two ends, there being about 50 feet of hose from Sample A, between the up-stream piezometer and the hydrant, and about 50 feet of hose (A) between the down-stream piezometer and the discharging nozzle. To enable the piezometric comparisons to be made with the minimum of error the two mercury gauges were set up side by side midway of the hose, and they were thus both observed almost simultaneously by one observer. Rubber tubes each about 29 feet long were thus necessary to reach from the gauge to the piezometer; but as the vertical rise of these tubes was very small, had air bubbles existed in the tubes they would have caused but almost inappreciable error. Much care was taken, however, to prevent the existence of air bubbles, by blowing off the tubes through cock at gauge before each experiment. To prevent so far as possible cross-currents from interfering with accuracy of piezometers, that portion of the hose within at least 5 feet of each piezometer was carefully straightened before each experiment. The discharge was in each case measured in the tank as already described; and there is no reason to think that error in determination of rate of discharge exceeded ½ of 1 per cent., and no reason to think that error in the comparative readings of the two pressure gauges could have been greater than 0.10 pound. The results are given in the following table:

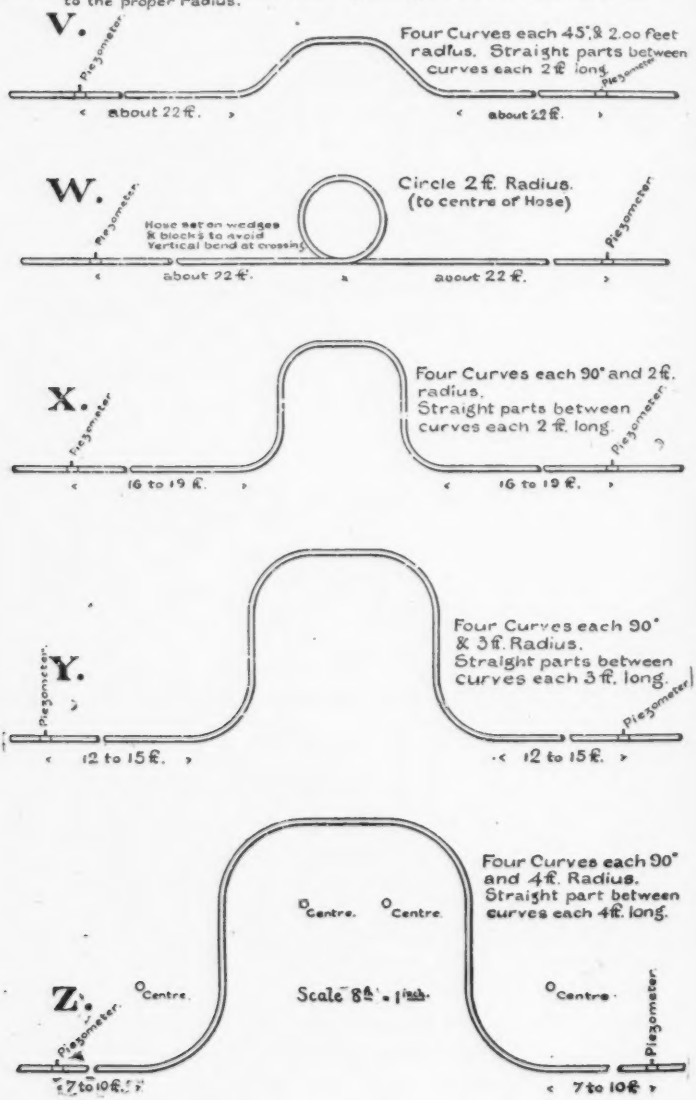
TABLE No. 8.—Experiments on Resistance due Curves.

Time. H. M.	Quantity flowing measured in Tank, gallons per minute.	Observed loss of pressure between piezometers, pounds.	Mean flow to which observations are reduced, gallons per minute.	Mean Velocity in hose, feet per second.	Loss that would have existed with mean flow, pounds.	Increased resistance due curve, pounds.	Ratio of loss due whole curve to head due velocity in hose.	
September 24th.	Hose like	Sample *D*.	Diameter 2.49	inches.	Length 57.2	feet.		
2 17	259.6	9.65	258.0	17.0	9.57	.....	.....	Hose straight at beginning of Expts.
6 14	259.5	9.73						" " " end " "
6 24	294.1	12.30	293.0	19.3	12.22	.....	.....	" " " end " "
6 26	324.3	14.62	323.0	21.3	14.57	.....	.....	" " " beginning " "
6 38	325.0	14.77						" " " end " "
3 16	258.1	10.05	258	.....	10.04	0.47	.24	Hose bent around four 45 degree curves of 2 feet radius. See *V*, Fig. 51.
3 24	293.2	12.68	293	.....	12.66	.44	.17	
3 33	323.5	15.22	323	.....	15.18	.61	.20	
3 01	257.3	10.08	258	.....	10.13	0.56	.29	Hose bent around one full circle of 2.0 feet radius. See *W*, Fig. 51.
2 52	293.4	12.93	293	.....	12.90	.68	.27	
2 43	323.7	15.46	323	.....	15.40	.83	.27	
4 40	257.6	10.20	258	.....	10.23	.66	.34	Hose bent around four arcs of 90 degrees of 2 feet radius. See *X*, Fig. 51.
4 25	292.7	12.94	293	.....	12.96	.74	.29	
4 11	324.3	15.43	323	.....	15.33	.76	.25	
6 05	257.9	10.32	258	.....	10.33	.76	.39	Hose bent around four arcs of 90 degrees of 3 feet radius. See *Y*, Fig. 51.
5 55	293.7	13.00	293	.....	12.95	.73	.29	
5 48	322.6	15.59	323	.....	15.62	1.05	.24	
5 23	257.9	10.42	258	.....	10.43	.86	.44	Hose bent around four arcs of 90 degrees of 4 feet radius. See *Z*, Fig. 51.
5 32	292.3	13.14	293	.....	13.19	.97	.39	
5 40	322.5	15.69	323	.....	15.73	1.15	.38	
	Smilar experiments with hose from Sample *A*. Diameter 2.64 inches.							
September 25th.								
2 52	305.1	8.62	304	17.7	8.55	.....	.....	Hose straight at beginning. Length, 51.8 feet.
4 47	305.4	8.63	304	.....	8.55	.....	.....	Hose straight at end.
4 24	304.3	9.06	304	.....	9.04	.49	.23	Hose bent around four 90 degree arcs of 2 feet radius. See *X*.
4 38	304.2	9.29	304	.....	9.28	.73	.35	Hose bent around four 90 degree arcs of 3 feet radius. See *D*, *Y*.
4 09	302.7	9.24	304	.....	9.32	.77	.37	Hose bent around four 90 degree arcs of 4 feet radius. See *E*, *Z*.

Resistance due Curves in Fire Hose. **Fig. 51.**

Form of curves Experimented upon.

Hose laid on flat floor and held in place by form jig-sawed from 3 inch plank to the proper radius.


V.
Piezometer.
Four Curves each 45° & 2.00 feet radius. Straight parts between curves each 2 ft. long.
Piezometer.
about 22 ft.
about 22 ft.
W.
Piezometer.
Hose set on wedges & blocks to avoid Vertical bend at crossing.
Circle 2 ft. Radius. (to centre of Hose)
Piezometer.
about 22 ft.
about 22 ft.
X.
Piezometer.
Four Curves each 90° and 2 ft. radius. Straight parts between curves each 2 ft. long.
Piezometer.
16 to 19 ft.
16 to 19 ft.
Y.
Piezometer.
Four Curves each 90° & 3 ft. Radius. Straight parts between curves each 3 ft. long.
Piezometer.
12 to 15 ft.
12 to 15 ft.
Z.
Piezometer.
Centre.
Centre.
Centre.
Four Curves each 90° and 4 ft. Radius. Straight part between curves each 4 ft. long.
Scale 8 ft. = 1 inch.
Piezometer.
7 to 10 ft.
7 to 10 ft.

It will be noted that the sequence of the experiments with different radii was made irregular, in order to break up any periodic error, and that agreement of the repetitions indicates that any accidental distortion of the hose could have influenced the result but little.

The several curves experimented upon were made nearly midway between the piezometers and were of the form shown in Fig. 51.

Excepting *V*, the total curvature was in each case 360 degrees. Between each of the curves was straight tangent of length equal to radius of hose. The hose was laid on a flat floor and held accurately in place by pieces of 3-inch plank jig-sawed to the proper radius, and much care was observed in placing it in order that it might not be wrinkled on the inner side or flattened on the outer side of curve. This was attained by bending and placing it under full pressure. Careful calipering indicated that it retained its cylindrical form. Two feet radius was about as sharply as it could be bent, however, and retain this smooth cylindrical form. The difference in pressure at the two piezometers was first measured with the hose lying straight; then, without shutting off the flow or disturbing the pressure within the hose, the hose was bent around some one of the curves and the loss of pressure between the piezometers again measured. Gauges were read at intervals of fifteen seconds and each value as here given is thus the mean of about fifteen observations. The water pressure was fairly steady, the extreme range in the course of the fifteen observations seldom if ever being more than $\frac{1}{2}$ pound, and generally not more than $\frac{2}{10}$ pound.

As the results came out different from what were expected, some further experiments were made next day with another kind of hose, namely, Sample *A*, a remarkably smoothly finished piece of solid rubber hose, the interior of which was almost as smooth as lead pipe.

The above results are remarkable, and it is to be regretted that there was no means of extending the series down to shorter radii, or of investigating that loss due to the bending which may perhaps have continued within the straight pipe down stream from the end of curve.

It seems pretty clearly proved that within these limits there was more loss with the large radius than with the small. This same condition was indicated by the experiments of September 14th, under somewhat different conditions. Perhaps the reason for this is that the arc was longer and thus there was a greater length of pipe in which the current was disturbed.

Shall the Standard Diameter for Fire Hose be Increased?

To illustrate the effect of diameter of hose upon the loss of pressure by friction the following table is presented. This is computed by the well established law that loss of pressure varies inversely as the fifth power of diameter:

For any definite number of gallons per minute flowing, the loss of pressure due friction per 100 feet of hose, whose diameter is		3	inches is only	40	per cent.	as much as in hose of the same smoothness, whose diameter is exactly 2½ inches.	
do	do	2⅞	"	50	"	do	do
do	do	2¾	"	62	"	do	do
do	do	2⅝	"	78	"	do	do
do	do	2½	"	29	"	more than in hose of the same smoothness, whose diameter is exactly 2½ inches.	
do	do	2⅜	"	70	"	do	do
do	do	2¼	"	2.	times as much as in 2½-inch hose.		
do	do	2.	"	3.05	"	"	"

This table is well worthy of study by makers of hose.

By way of further illustrating the practical bearing of this question of diameter, we may say that if the Boston Woven Hose Company, for instance, should increase the diameter of hose like sample *D*, in Table No. 6, on page 348, by $\frac{3}{16}$ inch, thus making it same size as sample *E*, the observed friction loss for each hundred feet of length would be 10 pounds instead of 14.5 pounds, as found, or a saving of 31 per cent. of power now wasted.

And as a further illustration we may venture the suggestion that if some enterprising firemen, who earnestly desired the prize for distance playing at a firemen's muster, should have some hose smooth as sample *C* or *D* (see Fig. 47), manufactured with internal diameter of 2¾ inches instead of 2½, but fitted with the ordinary 2½-inch coupling, this difference in diameter, though so small as to be almost unnoticeable, especially if hose were, like sample *D*, made without a jacket, would, with the customary 250 feet of hose and a 1⅛-inch stream, make more difference in the distance reached than would any fancy nozzle; and, in comparison with hose of the same smoothness, 2½ inches in diameter, would, with the same pressure at engine, throw the extreme drops about 15 or 20 feet farther. With greater length of hose than 250 feet the difference would be very much more marked.

From strong practical reasons, this slightly increasing diameter of such brands of cotton rubber-lined hose, as are now made exactly 2½ inches diameter, is well worthy consideration, especially by the makers

of woven hose. (In knit hose, solid rubber hose and leather hose, a somewhat increased size is at present attained by the natural expansion under pressure, as shown on page 353.)

The 2½-inch standard was first adopted years ago, before pumps or steam fire engines had attained their present perfection, delivery or capacity, and before the costly experience gained in large mill fires, as well as in the large fires of Portland, Chicago and Boston, had led to a general increase in size of streams thrown at serious fires.

Costly experience has shown that in serious fires a small stream is evaporated as it falls in spray through the flames, while if a large stream is thrown enough may escape the evaporation to pass through the heated gases and reach the burning coals themselves. Streams large in volume are thus a necessity.

In a well designed and first-class, modern, mill-hydrant system, lines of hose more than 250 feet in length will not, as a general thing, be necessary; and the friction loss in hose is thus in one sense of less importance there than in much of the work of a city fire department, where lines upward of 500 feet in length are often used.

Considering the needs of city departments, the writer believes it would be of much practical advantage for ordinary fire hose to be at least of 2¾ inches diameter; this to be fitted up for the present, however, or until favorable experience fully proves the advantage of a general change, with a coupling of 2½ inches bore, so as to be perfectly interchangeable with hose at present in use. Such a hose would, with the same pressure at hydrant or steamer, give a stream at the end of 1 000 feet of hose, equally large and strong as would be thrown at the end of a line about 650 feet long of 2½ inches diameter.

The only objections to its use are, first, the increased weight to handle. This cannot be considered insurmountable, in view of the fact that much knit hose now in use is, when expanded by pressure, of nearly this size, and is handled without difficulty. Moreover, a length or two of light unjacketed 2½-inch hose could be used next nozzle for inside work or work on ladders. The second objection is the reduced bursting strength due the larger diameter. This, with the fabric remaining just the same, would amount to only 10 per cent., and any fabric now standing 500 pounds on 2½ inches diameter would stand 450 pounds on the 2¾ inches diameter. In fact, the best 2½-inch jacket fabrics of to-day are plenty strong enough to stand a 3-inch diameter, and I incline to the

opinion that it may be best not to stop content with the 2¾-inch diameter, but to go far enough while we are about it and adopt a 3-inch diameter as the standard for fire hose.* Before going too far in this recommendation I should like to see the result of an outfit of such hose in the fire department of some large city for six months, and learn if the men found it too heavy, or found practical difficulty in its manipulation. Ultimately a standard 3-inch coupling should be adopted, and somebody, preferably the National Association of Fire Engineers, should decide on an appropriate thread, which should be standard and universal from Montreal to Mexico. There are now upward of 200 different "standard" threads† in use for 2½-inch hose, and this sad confusion has many times led to serious damage and delay, and more than once rendered aid summoned from neighboring towns during a serious conflagration of little avail. While the matter is in a tentative state I would advise using this 3-inch hose on the coupling of 2½ inches bore, in order that it might fit ordinary hydrants and engines and be perfectly interchangeable with the old standard hose. The couplings should, however, be designed and made with care, avoiding a square shoulder where diameter is reduced from 3 to 2½, and making this reduction or enlargement in every case by long, easy, round cornered taper.

If the reduction of diameter is made in this manner, the loss by using the 2½-inch interchangeable coupling will be much less than would at first thought be expected, and the loss of pressure by such a coupling at each fifty feet would be less than 5 per cent. of the pressure saved by the larger size of hose.

Experiments on Effect of Reduction of Diameter at Hose Coupling.

A few experiments were made to see what extra friction loss would be caused by couplings of 2¼ inches bore on 2½-inch hose. The old-fashioned tail couplings for 2½-inch hose had a waterway of but 2¼ inches in diameter. These were the kind used in Weston's experiments, and it was desirable to know how far this constriction of waterway modified his results.

These experiments were made by taking a line of 2½-inch hose about

* The above was written about a year ago and submitted to Mr. Reed, Treasurer of the Eureka Fire Hose Company of New York, and others.

I am pleased to note that the Eureka Company have acted on this matter and have already equipped several departments with trial outfits of 3-inch hose, and from them learn that the result so far is most encouraging.

† The Chapman Valve Company have gauges for 200 different patterns of 2½-inch hose-coupling threads in regular use in various cities and towns of the United States. And A. J. Morse & Son, of Boston, make 2½-inch hose-couplings to upward of sixty different gauges.

300 feet in length, having full size 2½-inch couplings, and after having carefully determined, by the methods already described, the loss of pressure in its length for certain rates of flow, water was shut off, and the joints between the six 50-foot sections of hose uncoupled, and bushings consisting of tubes $4\frac{6}{10}$ inches long, with 2¼ inches diameter of waterway and square ends, were inserted at each of these five joints. The joints were then coupled up again, and the loss of pressure determined for the same rates of flow as before. One of the couplings without the bushing is shown in Fig. 52, and a coupling containing a bushing is shown in Fig. 53.

Hose Couplings.

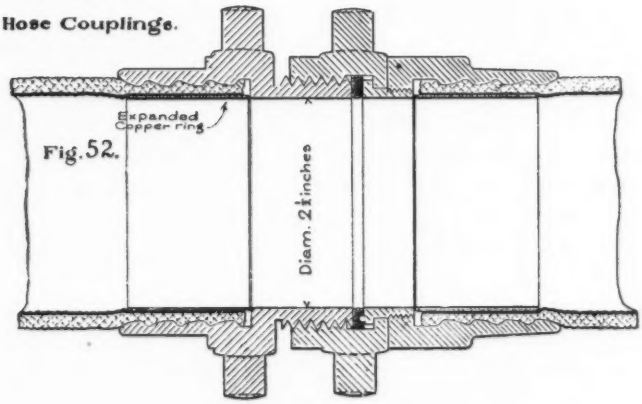


Fig. 52.

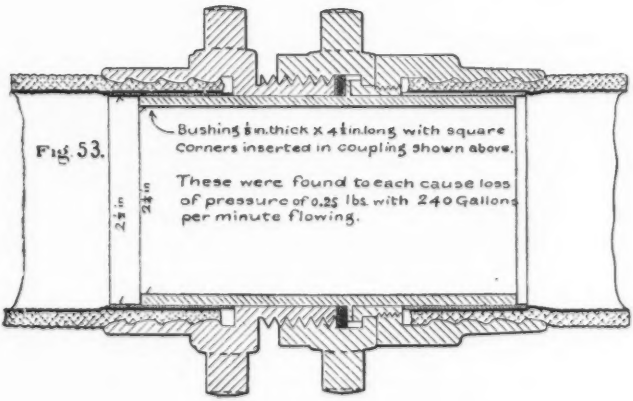

Bushing ⅛ in. thick x 4 in. long with square corners inserted in coupling shown above.
These were found to each cause loss of pressure of 0.25 lbs. with 240 Gallons per minute flowing.
2¼ in.
2¼ in.

Fig. 53.

Two entirely independent sets of experiments were made, one set with solid rubber hose (sample B), and the other with cotton rubber lined hose (sample H).

Date of experiments	September 5.	September 16.
Kind of hose	Solid rubber (B).	Rubber lined (H).
Average internal diameter of hose	2.60 inches.	2.63 inches.
Average internal diameter of couplings	2.53 "	2.51 "
Average internal diameter of bushings	2.23 "	2.23 "
Number of independent experiments	4	3
Average number of gallons per minute flowing in hose	211.7	206.9
Average increased loss of head due inserting five bushings	1.01 pounds.	0.95 pounds.
Loss of head due each bushing*	0.190 "	0.202 "

From the above experiments we deduce that with 240 gallons per minute flowing the effect of such a square shouldered reduction of waterway at hose coupling from $2\frac{1}{2}$ to $2\frac{1}{4}$ inches would be to cause a loss of 0.25 pounds at each bushing, or 0.50 pounds additional loss per 100 feet of hose.

If up-stream end or entrance of bushing had been rounded and discharging end tapered out to full diameter, the loss due the reduction of area at couplings could have been made much smaller, or probably less than half the above amount.

---

* These results agree very well with theory that loss by impact due a sudden reduction of velocity equals head due the difference of the velocities. (See Professor Swain's notes on Hydraulics, page 36, or Professor Merriman's Hydraulics, page 149.) Co-efficient contraction at upper end of bushing will be 0.83 (per Cox's Weisbach, page 841). Therefore, velocity in contracted portion is 20.95, and in passing to uncontracted portion of bushing velocity is there 17.39, from which sudden reduction of 3.56 feet in velocity there results a loss of 0.20 feet head; and again, in passing from bushing into hose, velocity is reduced to 12.79 feet per second, a reduction of 4.60 feet, for which the corresponding loss of head is 0.33 feet.

Thus, the total loss by this theory would be $.33 + .20 = .53$ feet, or 0.23 pounds, instead of 0.20, as actually found.

Loss of Head due to Reduction of Area of Hose by Washers at Coupling.

In coupling hose, use is frequently made of washers which are a little smaller than proper. As it took but little time to make, in course of the experiments already described, a few experiments on this subject, it was done. It is hardly worth while to describe the experiments in detail; but we may say that in three cases, immediately after the regular experiment in which washers of full bore of hose were used, these 2½-inch washers were taken out and other washers with hole about 2¼ inches diameter (actually 2.28 inches) inserted in their place, and the friction loss through the hose with these small washers again determined. Then these 2¼-inch washers were in turn replaced by washers with 2.00-inch hole, and the experiment again repeated for two quite different velocities of flow. The washers were of a firm quality of rubber and about $\frac{3}{16}$-inch thick, evenly moulded, and with sharp corners, and probably retained nearly their original form during the experiment. For convenience of comparison the results are reduced to the basis of 240 gallons per minute (a first class 1⅛ inch fire stream) flowing in hose, and average as follows:

Loss caused by insertion of Washers 2.28-inch Diameter in 2½-inch Hose Coupling.

Sept.	4th.	Hose=Sample	*K.*	Average loss for each washer,			0.48	pound.
"	6th.	" "	*B.*	"	"	"	0.49	"
"	10th.	" "	*D.*	"	"	"	0.70	"
		Average.....					0.56	"

Loss caused by insertion of Washers 2 inches Diameter in 2½-inch Hose Coupling.

Sept.	4th.	Hose=Sample	*K.*	Average loss for each washer,			2.61	pounds.
"	6th.	" "	*B.*	"	"	"	3.56	"
"	10th.	" "	*D.*	"	"	"	3.15	"
		Average.....					3.11	"

Under the ordinary theory that in constrictions of area like this the loss of pressure equals the head due the difference in velocities, and

assuming that the co-efficients of contraction found in experiments on ring nozzles apply here, we should expect for the

Washer with hole 2.28 inches diameter, a loss of..... 0.51 pounds.
" " " 2.00 " " " ..... 2.39 "

The actual loss is from 14 to 30 per cent. greater than this, but the agreement is satisfactory, in view of the yielding nature of the diaphragm. We compute, therefore (by adding 25 per cent. to theoretical loss as deduced above), that in hose with 2½-inch couplings the loss due use of washers smaller than hose will be as follows:

Inside Dimension of Washers.	For Flow of 200 Gallons per Minute.		240 Gallons per Minute.		300 Gallons per Minute.	
	Loss due each Washer.	Loss per 100 Feet of Hose.	Loss due each Washer.	Loss per 100 Feet of Hose.	Loss due each Washer.	Loss per 100 Feet of Hose.
With 2⅞-inch hole.....	0.10 lbs.	0.20 lbs.	0.15 lbs.	0.30 lbs.	0.23 lbs.	0.46 lbs.
" 2½ " "	.52	1.04	.75	1.50	1.17	2.34
" 2½ " "	1.16	2.32	1.67	3.34	2.61	5.22
" 2 " "	2.08	4.16	2.99	5.98	4.67	9.34

Experiments on Jets.

The site of all the jet experiments recorded in Tables Nos. 9, 10 and 11 is shown in Fig. 54. The site of the experiments recorded in Table No. 12, for determining greatest horizontal distance that could be thrown with a given pressure, is shown in Fig. 55.

The experimental data previously on record for height reached by jets is very scanty indeed, and some of the writers apparently fail to recognize how few are the experiments on which existing tables are based. Thus it is stated in the most recently published treatise on hydraulics ("A Treatise on Hydraulics," by Mansfield Merriman, Wiley and Sons, 1889, page 132) that "the experiments of Ellis determine the height and range to which jets may be thrown," etc., and then follows a table for vertical jets, giving a synopsis of his conclusions. Now, in point of fact, Ellis says he made no experiments on vertical jets, but says these figures in his tables are from the published figures of J. Herbert Shedd, M. Am. Soc. C. E. Tracing them back a step further, we find Mr. Shedd made no such experiments; but that certain tables were prepared at his direction by E. B. Weston, M. Am. Soc. C. E., and by Charles H. Swan, M. Am. Soc. C. E. Subsequently Mr. Weston made a further study of the subject, and the data used and the conclusions reached were presented to this Society by Mr. Weston in a paper read September, 1884.

Mr. Weston, in turn, in preparing these tables made use of no experiments of his own on height reached by jets, but compiled and compared with the data given by Box a few additional experiments, viz., some experiments by J. Foster Flagg, M. Am. Soc. C. E., on an orifice which bore but little resemblance to a hose nozzle, and also some experiments by Mr. S. Van Cleve, in which the determination of the pressure was rendered uncertain by being measured at a point on a line of hose 50 feet distant from the nozzle, and which experiments show a good deal of variation among themselves. Finally Mr. Weston simply made use of the formula given in Box's Hydraulics. Thus it happens that the tables of Merriman, Ellis and Shedd for vertical jets merely repeat the table and formula in Box's Hydraulics without change (see pages 38 and 39, 6th Edition). Box, in presenting his table, says: "There are very few reliable experiments on this subject," and that "more experimental information is very desirable," and gives his formula as merely a tentative one.

High jets are a difficult subject for accurate experiment, and the result of my experiments shows that though Box's empirical formula is incorrect in some of its details, yet his general result is somewhere near correct within the range of sizes common for fire streams, and it is found to be much more accurate than would naturally be expected in view of the incompleteness of the data with which Mr. Box had to work.

This is illustrated by the following comparison :

Hydrostatic Pressure.	¾-inch Nozzle. Height of Jet by Box's Formula.	¾-inch Nozzle. Height of extreme Drops by Freeman's Experiments.	Error of Box Formula.	1¼-inch Nozzle per Box.	1¼-inch Nozzle per Freeman.	Error of Box Formula.
Feet. Pounds.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
57.7 = 25 0	50.8	49.4	+ 1.4	53 5	51.2	+ 2.3
100.0 = 43.3	79.0	82.5	— 3.5	87.5	88.0	— 0.5
115 5 = 50.0	87.7	92 3	— 4 6	98.8	101.2	— 2.4
161.6 = 70.0	107 3	113.5	— 6 2	129 0	134.8	— 5.8
200.0 = 86.6	116.7	127.0	— 10.3	150.0	150.7	— 0.7
230.9 = 100.0	120.0	133.2	— 13.2	164.4	158.9	+ 5.5

It will be seen, however, on examining the experiments presented below, and from the plotted curves of Fig. 56, that they plainly indicate that the loss of height due to resistance of air for jets of large diameter varies, according to a law, somewhat different from that implied by the Box formula.

Effect of Wind.

Since making these experiments on jets, I am disposed to regard with suspicion the high accuracy of any experiments on high jets which are not described with the fullest detail as to stillness of air. We were surprised at the extreme sensitiveness of height of jets at 40 pounds or more pressure, to even very faint wind. On three or four different days a slight breeze sprang up just as experiments on jets either vertical or at 75 or 60 degrees elevation were being commenced, and it was found that even a moderate summer afternoon zephyr would cut down the height of the extreme drops by fully 10 per cent. Thus, on September 15th, with 1¼-inch smooth nozzle set at 60 degrees elevation and under about 50 pounds water pressure, a breeze rather suddenly sprang up, blowing in direction of jet. It at once reduced height of the extreme drops from 82 to 67 feet. This was merely a "moderate to fresh" breeze, and from a station on the mill roof I very roughly estimated its velocity at from 8 to 12 miles per hour.

Again, on September 24th, when trying to experiment with a 2-inch jet from a Siamese pipe set at 60 degrees elevation and with about 50 pounds pressure on nozzle, I found that with a fresh breeze coming in occasional gusts in direction against the stream, the extreme height of the stream was 10 feet greater in the lulls than while wind was blowing.

On another occasion, when experimenting on the maximum horizontal distance that a jet could be thrown, it was found that a gentle breeze, apparently of about 6 feet velocity per second, blowing in direction opposite to jet reduced the distance attained by the extreme drops from 125 to 100 feet.

I had much difficulty in finding a day sufficiently calm for satisfactory experiments, and sometimes, when it would seem calm down on the ground, on going to the mill roof breeze enough would be found to interfere materially with accuracy.

For six weeks, while engaged on the other experiments recorded in this paper, we kept apparatus in condition so it could be quickly arranged for jet experiments, and we continually kept watch of the smoke from the neighboring tall factory chimneys, and also kept watch of a little flag which we hung near the position of summit of jet. Several times we started our jets and had to give up on account of effect of a slight wind being plainly evident. In the course of the six weeks we found only a very few brief periods when the air was calm, and that the experiments on jets now presented are in some respects less extended and complete than I desired, is due to the fact that these periods of still air were so very few and so brief.

So very marked was the effect of currents of air, as to leave no doubt that the remarkable records for distance-playing sometimes made at firemen's musters are due to some favoring flaw of wind rather than to any peculiar excellence of form of nozzle used.

The site and general arrangement of the apparatus is shown by Figs. 54 and 55 so clearly as to need but little further description. It is to be clearly understood, however, that in the final experiments upon which tables are based, only one nozzle was used at a time. The two views just mentioned both illustrate experiments for comparing the relative merits of two nozzles, and when thus using two nozzles near together, there was apparently a slight and equal increase in the distance reached by both streams, due to the air currents set in motion by the jets themselves.

VERTICAL JETS AND JETS AT ELEVATIONS OF 60 AND 75 DEGREES.

As may be judged from an inspection of Fig. 54, the facilities for accurate observation were of unusual excellence, by reason of the convenient position of the roofs of these very large and high mills.

The writer stood generally upon the Washington Mill roof, and from this position noted the height of jet; occasionally he stood on the Pacific roof, and from that point noted the character of jet as to fineness of drops, etc., which from that station could be seen with great distinctness; but as the two mills were only about 50 feet apart, the jet could also be observed with great distinctness from the Washington roof.

As there were windows at each story in the end of the Washington Mill, observations upon jets at a less height were also readily made. The joints of the brick-work in the blank end-wall of the Pacific Mill served a convenient purpose in making it resemble a large "cross-section sheet," against which the jets were seen projected, and by sighting past a horizontal or vertical bar conveniently located, it was easy to refer any point to the co-ordinates for height and distance as marked on the two masts and on the wall.

There was of course a little parallax at times due to the observer's position, but the writer was careful to bear this in mind, and to allow for it according to his best judgment. I took several instantaneous photographs of the jets; but a very wide angle lens had to be used, and in general the conditions were not favorable for good photographic work, and as the periods of still air were found to be so few, very little time for photographic records could be afforded.

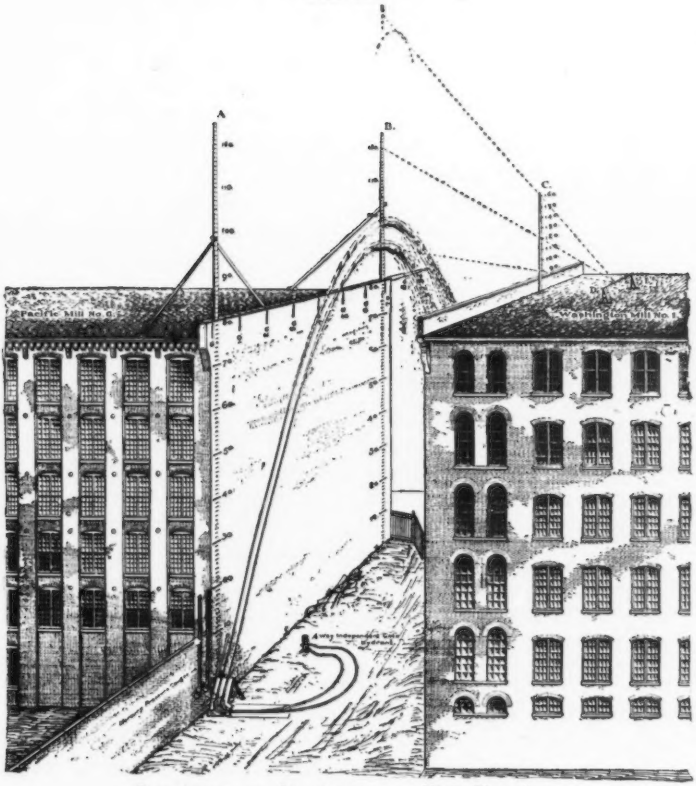
Water was supplied from the city reservoir in nearly all cases where pressure at base of play-pipe was not more than 50 or 60 pounds. For higher pressures the rotary fire-pumps were used.

Generally speaking, the pulsation of jet was not excessive, and in all cases the jet was carefully watched for some little time and the mean value recorded.

I consider that any existing errors of observation on extreme height of jet due to a given pressure are due to air currents more than to any other cause.

There is a good deal of irregularity in the observations on extreme distance as a "good fire stream," but this is due to the indefiniteness of determining just what constitutes this.

FIG. 54.



Experiments on Fire Streams at High Elevations.

The final experiments on which tables for height of jets are based were made at this site, but in these only one nozzle was used at a time.

Sketch illustrates experiments to determine which of two nozzles (ring or smooth, for instance) was the better, or would throw stream highest and with the least spraying,—pressure at base of each play-pipe being the same. For this the two 50-ft. lines of hose leading to play-pipes were of same kind; bends in hose at base of play-pipe were carefully laid flat on the inclined platform, as shown, and clamped between blocks jig-sawed from 3-in. plank, so each hose lay in flat curve of 3 feet radius. 1 to 2 feet of hose next base of play-pipe was straight.

The masts, A and B, were graduated in feet, and reached to a height of 124 feet above nozzle. Below the masts, scales, made of strips of wood strung on heavy steel wire, marked each foot in height along face of wall.

Horizontal distances from end of nozzle were marked by wooden rods 10 feet apart, nailed to top of wall, as shown.

When height of jet was more than 130 feet, the mast, C, and sighting bar, D, were used in estimating height, proper allowance being made for parallax.

The play-pipes and their supporting platform could be set at any angle of elevation required, and securely clamped.

End of nozzle was set level with zero of mercury pressure gauges and zero of scale of height.

An assistant regulated pressure to within one-tenth of a pound by valves at hydrant, and, when all was ready, one observer read the mercury gauges each half minute, while another observed and noted height and characteristics of jet, as seen from the mill roofs.

Apparatus.

The mercury gauges shown in Fig. 1 and piezometers of form shown in Fig. 2 and already described, were used exclusively in all the experiments which are recorded below. Generally speaking, the mean pressure was thus determined with certainty within ½ pound per square inch. The height marks, at corners of Pacific Mill, were made of strips of board strung on stout steel wire. These were first adjusted on a level floor at the proper distances by aid of a steel tape. The strips of board were then conspicuously figured with black paint and hoisted into position. The masts *A* and *B* were similarly graduated by means of a steel tape. and conspicuously marked and figured before hoisting.

The angles of elevation for the jets at site shown in Fig. 54 were set off by the aid of a very large and accurate vernier protractor. This was used directly to set two batter boards or straight edges each 4 inches wide, 16 feet long, which were nailed to the wall at angles of 60 and 75 degrees respectively, with error of angle probably not exceeding one minute. As each play-pipe was clamped to the supporting frame, it was carefully adjusted by sighting the center line of jet or rather the mean of its edges out of wind with the straight edge above mentioned, and thus it is probable that jets did not vary by so much as ten minutes of arc from 60 or 75 degrees.

Height as Good Fire Stream.

The determination of this was a matter to which the writer gave much attention, because of the fact that a knowledge of height of the extreme drops is of comparatively little practical value to the fireman although of much interest to the physicist, and also because of the fact that tables of "height of jets" in all the text books, pump catalogues, etc., being really the height for the extreme drops, while height as a good practical fire stream was only about two-thirds as much, has sometimes led to serious misunderstandings.

The extreme limit at which a jet can be called a "good fire stream" is not sharply defined, but is to a considerable extent a matter of judgment. It was hard to define the exact limit, and say within 5 feet, or in some cases even within 10 feet, just exactly where the stream ceased to be good. The plotted observations show this by the way they jump

about, but it was the intention that the various estimates should be independent. To give a clearer idea of just what I had in mind, the following statement is presented:

In recording the maximum distance to which the jet attained in such shape that it could be classed as a good fire stream, I classed as such:

First.—A stream which at limit named had not lost continuity of stream by breaking into showers of spray.

Second.—A stream which up to limit named appeared to shoot nine-tenths of whole volume of water inside of a circle 15 inches diameter and three-quarters of it inside a 10-inch circle, nearly as could be judged by the eye.

Third.—Which would probably be stiff enough to attain in fair condition the height or distance named, even though a fresh breeze were blowing.

Fourth.—Which at limit named would, with no wind, enter a room through a window-opening and barely strike ceiling with force enough to spatter well.

It will be noted that plottings of these distances as "good" and "fair" streams jump about irregularly, and my mean curve for "good fire streams" should not be considered strictly definite within, say, 10 or 15 per cent.

Very likely many would class a stream as a "good fire stream" up to the point where I classed it as "fair," but I endeavored to allow a fair margin for effect of wind. The adjustment of the curves of Figs. 56*b* and 57*b* for the several sizes of nozzle for limit of good streams was guided mainly by analogy from the distance apart of the curves for extreme horizontal and vertical distance.

To sum this whole matter up, I feel some confidence that my classification as to extreme point at which stream could be called "good" or "fair" is in general agreement with these terms as they would be used by the average intelligent and experienced fireman.

The maximum horizontal distance for good streams may be exceeded considerably under favorable conditions. No correction for the very small amount of pressure absorbed by friction within the 2 to 3 feet of length of play-pipe between gauge and nozzle proper has been made (except in case of the 2-inch nozzle on Siamese) in plotting the results.

The following tables give the results of experiments in detail:

TABLE No. 9.

Experiments on Vertical Jets.

(See Figs. 56 and 56*b* for plotting of these observations.)

October 5th, 1888, Temperature of air..... 64 degrees.
Temperature of water..... 48 degrees.
Barometer (about)..... 30.0 inches.

No. of Experiment	Size and Kind of Nozzle. (See figures on pages 16 to 23.)	Pressure above Orifice shown by Gauge connected at Base of Play pipe. Pounds.	Discharge of Nozzle. Gallons per Minute.	Correction for Velocity past Gauge. Pounds.	Static Pressure above Orifice. Pounds per Square Inch.	Computed Static Pressure above Orifice. Feet.	Observed Elevation of Jet above End of Nozzle.		
							Average of Highest Drops. Feet.	Mean Average Summit of Jet. Feet.	Height attained by three-fourths of Water. Feet.*
1	$\frac{3}{4}$ smooth (*a*)	60.2	130	.48	60.7	140.2	105.	102.	90.
2	" " "	49.9	117	.38	50.3	116.1	91.	90.	83.
3	" " "	40.2	105	.31	40.5	93.5	78.	76.	72.
4	$\frac{7}{8}$ " (*b*)	49.5	161	.73	50.2	115.9	94.	93.	85.
5	" " "	40.0	145	.60	40.6	93.7	80.	78½	75.
6	1 " (*c*)	62.4	236	1.61	64.0	147.8	124.	120.5	110.
7	" " "	50.1	209	1.26	51.4	118.7	100.	98.5	94.
8	" " "	40.0	187	1.01	41.0	94.7	82.	81.	77.
9	$1\frac{1}{8}$ " (*d*)	58.0	288	2.37	60.4	139.9	120.	115.	105.
10	" " "	50.2	267	2.05	52.3	120.8	105.	103.	88.
11	" " "	45.2	254	1.86	47.1	108.8	94.	92.	81.
12	" " "	40.1	239	1.64	41.7	96.3	84.	83.5	78.
13	" " "	35.1	223	1.44	36.5	84.3	75.	74.6	68.
14	" " "	30.0	206	1.23	31.2	72.0	64.5	64.	61.
15	" " "	25.0	188	1.01	26.0	60.0	53.	52.8	50.
16	" " "	20.0	169	.81	20.8	48.0	43.	42.8	42.
17	" " "	15.1	147	.62	15.7	36.2	32.4	32.2	31.5
18	" " "	10.0	119	.40	10.4	24.0	21.4	21.2	21.
19	$1\frac{1}{4}$ " (*e*)	53.7	343	3.40	57.1	131.8	115.5	114.5	110.
20	" " "	49.8	330	3.16	53.0	122.4	106.5	105.5	103.
21	" " "	40.2	296	2.51	42.7	98.6	86.	85.5	85.
22	$1\frac{3}{8}$ " (*f*)	48.5	393	4.45	53.0	122.4	105.	103.5	95.
23	" " "	45.1	378	4.05	49.2	113.6	100.	98.	90.
24	" " "	40.1	357	3.66	43.8	101.1	88.5	87.5	80.
25	" " "	35.2	335	3.25	38.5	88.9	77.	76.4	75.
26	2-inch Siamese	49.9	847	2.27	52.2	120.5	106.	103.	100.
27	" "	40.1	760	1.83	41.9	96.7	85.	84.	80.
28	" "	30.1	658	1.89	32.0	73.9	65.	64.	62.

NOTE.—In plotting experiments 26-28, 2 per cent. was added to height as here given to allow for head absorbed b friction in elbow, etc.

In all experiments in this table water was supplied from city reservoir.

Experiments on $1\frac{1}{4}$-inch and $1\frac{3}{8}$-inch nozzles made from 7.30 to 8.30 A.M.

" $1\frac{1}{8}$, 1, $\frac{7}{8}$, $\frac{3}{4}$ " " " 4.30 to 6 P.M.

" 2 " " " 10.30 to 11.15, October 11th.

* This proportion ($\frac{3}{4}$ of whole volume discharged) was estimated only by the eye, and is, therefore, a very rough approximation.

TABLE No. 9—(*Continued*).

Pulsation at Summit.	Actual Height less than Static Pressure.		Excess of Observed Height over Height Computed from Formula below.	Remarks.
	Highest Drops.	Mean Summit.		Temperature of water, 60 degrees; temperature of air, 64 degrees. In all these vertical jet experiments there was apparently much less water lost or detached from main stream on the way to the summit than when stream was inclined. Pulsations noted occur at intervals of 2 or 3 seconds; practically no wind; excellent conditions for observation; summit very well defined; stream holds together excellently; big drops and lumps of water at very top; nearly one-half of whole volume reaches summit.
Feet.	Feet.	Feet.		
3.	35.2	38.2	+ 0.1	
3.	25.1	26.1	— 0.9	Stream retains its integrity well up to 85 feet above nozzle.
2.	15.5	17.5	+ 0.2	Top is well defined, looks like an irregular solid lump of water.
2½	21.9	22.9	— 1.2	Good conditions for observing height certainly within ½ foot.
2.	13.7	15.2	— 0.2	
3.	23.8	27.3	+ 5.8	Summit of jet well defined.
2.	18.7	20.2	+ 0.3	
1.	12.7	13.7	— 0.6	
4.	19.9	24.9	+ 3.6	
2.	15.8	17.8	+ 1.7	
2.	14.8	16.8	— 0.6	Height of summit determined certainly within 1 foot.
1.5	12.3	12.8	— 1.2	
1.	9.3	9.7	— 0.8	
0.8	7.5	8.0	— 1.3	All the time, interference to jet from falling drops is very slight.
0.5	7.0	7.2	— 2.7	
0.5	5.0	5.2	— 2.2	Almost the whole of water forms a compact bunch to top.
0.4	3.8	4.0	— 2.2	
0.3	2.6	2.8	— 1.9	
2.	16.3	17.3	+ 2.5	
2.	15.9	16.9	+ 0.2	Excellent observation. Water lumpy at top.
1.	12.6	13.1	— 2.1	
2.	17.4	18.9	— 2.8	
2.	13.6	15.6	— 0.9	
1.5	12.6	13.5	— 2.6	This jet holds together to the very top.
1.	11.9	12.5	— 4.1	Effect of wind is so slight that water falls almost exactly vertically.
	14.5	17.5	— 6.7	There was a slight gusty wind, but these observations were taken in the lulls, and I don't think wind caused an error of more than 1 foot, if at all.
....	11.7	12.7	— 7.0	These were so sheltered as not to be affected by wind.
....	8.9	9.9	— 6.6	

The following formula has its constants based upon the above experiments:

$$J = h - .00135 \frac{h^2}{d}$$

In which J = Height in feet of average extreme drops.
h = Static head in feet at base of play-pipe.
d = Diameter, in inches, of jet close to nozzle.

TABLE No. 10.—Experiments on Jets at 75 Degrees Elevation.

(See Figs. 56 and 56*b* for plotting of these observations.)

September 24, Temperature of Air, 58 degrees.
October 2, " " 57 "
November 9, " " 52 "

Date. 1888.	No. of Experiment.	(Size and Kind of Nozzle. See figures on pages 16 to 23.)	Actual Pressure Above Orifice, Shown by Gauge Connected at Base of Play-pipe.	Computed Discharge of Nozzle. Gallons per minute.	Correction for Velocity Past Gauge.	Computed Static Pressure Above Orifice. Pounds per Square Inch.	Computed Static Pressure Above Orifice. Feet.	Observed Elevation of Jet above End of Nozzle.			
								Average of Highest Drops.	Summit of Center of Main Body.	Extreme Limit of Good Fire Stream.	Extreme Limit of Fair Fire Stream.
Nov. 9	29	¾-inch Smooth (*a*)..	101.0	169.	0.81	101.8	235.0	129.	122.	83.	90.
"	30	1 " (*c*)..	103.0	303.	2.65	105.7	244.1	154.	148.	90.	110.
Oct. 2	31	1 " (*c*)..	50.0	209.	1.26	51.3	118.5	95.	93.	76.	80.
"	32	1 " (*c*)..	40.1	187.	1.01	41.1	94.9	79.	78.	66.	70.
"	33	1 " (*c*)..	30.1	161.	0.73	30.8	71.1	61.	60.	49.	52.
"	34	1 " (*c*)..	20.1	134.	0.51	20.6	47.5	43.	42.	35.	38.
Nov. 9	35	1⅛ " (*B*)..	104.0	385.	4.28	108.3	250.1	155.	153.	100.	115.
Oct. 2	36	1⅛ " (*B*)..	50.3	267.	2.02	52.3	120.8	101.0	98.	81.	85.
"	37	1⅛ " (*B*)..	39.8	238.	1.63	41.4	95.6	82.	81.	70.	72.
"	38	1⅛ " (*B*)..	30.2	207.	1.24	31.4	72.5	62.	60.	51.	55.
"	39	1⅛ " (*B*)..	20.1	169.	0.81	20.9	48.3	44.	43.	36.	40.
Feb. 21	40	1⅛ " (*B*)..	9.7	.....	0.40	10.1	23.3	18.	18.	18.	.....
Nov. 9	41	1¼-inch Sawed off (*C*)..	99.5	373.	4.00	103.5	239.0	153.	148.	105.	115.
"	42	1¼ " (*C*)..	75.0	324.	3.04	78.0	180.1	139.	134.	85.	100.
"	43	1¼-inch Smooth (*c*)..	86.5	434.	3.88	90.4	208.7	157.	150.	100.	110.
"	44	1¼ " (*c*)..	75.7	406.	4.80	80.5	185.9	141.	135.	85.	104.
Sep. 24	45	1¾-inch Smooth Cone (*t*).	49.8	644.	1.35	51.2	118.2	98.	96.	75.	80.
"	46	1¾ " On big Siamese.	45.2	614.	1.21	46.4	107.1	90.	88.	70.	75.
"	47	1¾ " " "	40.5	581.	1.08	41.6	96.0	80.	77.	65.	72.
"	48	1¾ " " "	35.1	542.	0.94	36.0	83.1	69.2	67.5	55.	60.
"	49	1¾ " " "	30.1	503.	0.81	30.9	71.3	60.	58.5	46.	52.
Sept. 24	50	2-inch Smooth Nozzle (*s*)	50.3	820.1	2.12	52.4	121.0	100.	97.	78.	82.
"	51	2-inch On Big Siamese..	45.0	776.1	1.90	46.9	108.3	91.5	87.5	70.	76.
"	52	2-inch Rifle Barrel.. ...	40.5	736.	1.73	42.2	97.4	83.	80.	66.	70.
"	53	"	34.9	684.	1.50	36.4	84.0	71.3	69.7	57.	64.
"	54	"	30.4	640.	1.31	31.7	73.2	62.2	60.5	50.	56.
"	55	"	24.7	574.	1.05	25.7	59.3	53.8	51.3	42.	46.

Note.—In the plotting of experiments 50 to 55, on Fig. 56

TABLE No. 10—(*Continued*).

Observed Elevation of Jet above End of Nozzle.		Observed Horizontal Distance North from End of Nozzle.				Remarks.
Actual Height of Jet less than Static Pressure.		Of Summit of Jet.	Of Limit of Good Fire Stream.	Of Fair Fire Stream.	Of Outside of Jet where Striking Ground.	
Highest Drops.	Main Body.					
106.0	113.0	.....	.....	.....	.....	Stream tapers out to a thin fine spray at end.
90.1	96.1	.....	.....	.....	.....	More water lost by spray on way to summit than with larger nozzles.
23.5	25.5	45.	27.	30.	70.	During the eight experiments of October 2 there was very little wind, and the conditions were favorable for accurate observations.
15.9	16.9	37.	22.	27.	60.	In these eight experiments pressures observed each 15 seconds; thus pressure as here recorded is mean of five observations.
10.1	11.1	29.	15.	20.	50.	
4.5	5.5					
95.1	97.1	65.	.....	.....	.....	Practically no wind. Temperature of water 50 degrees Fahrenheit, air 52 degrees Fahrenheit. At 90 feet high three-fourths of all water shoots within a 1-foot circle; at 80 feet high I judge that eight-tenths of water shoots within a 1-foot circle.
19.8	22.8	45.	30.	31.	85.	
13.6	14.6	40.	27.	28.	70.	
10.5	12.5	30.	20.	22.	55.	
4.3	5.3	19.	13.	18.	40.	
5.3	5.3	.....	.....	.....	.....	This was a coherent solid stream to summit (Bourdon gauge used).
86.0	91.0					
41.1	46.1					
51.7	58.7	67.				
44.9	50.9					
20.2	22.2	51.5	26.			Values in this Column not sharply defined.
17.1	19.1	48.	.....	28.		This throws a good close stream at all pressures.
16.0	19.0	42.	23.	.....		
13.9	15.6	37.	20.	23.5		
11.3	12.8	32.	18.	21.		
21.0	24.0	47.	28.	31.	73.	Very calm. Excellent conditions for observing.
16.8	20.8	46.	25.	29.	70.	
14.4	17.4	42.	24.	27.	73.	
12.7	14.3	36.	21.	25.	66.	
11.0	12.7	33.	18.	22.	60.	
5.5	8.0	23.5	16.5	19.	50.	

2 per cent. is added to observed height to allow for loss of head in elbow and Siamese.

TABLE No. 11.

Experiments on Jets at 60 Degrees Elevation.

September 17th, 1888. Temperature of Air, 75 degrees. Temperature of Water, 67 degrees. Barometer (about) 30.0.

No. of Experiment.	Size and Kind of Nozzle.	Actual Pressure above Orifice shown by Gauge Connected at Base of Play-pipe.	Computed Discharge of Nozzle. Gallons per Minute.	Correction for Velocity past Gauge.	Computed Static Pressure above Orifice. Pounds per Square Inch.	Computed Static Pressure above Orifice. Feet.	Observed	
							Average of Highest Drops.	Summit of Center of Main Body.
56	⅞-inch smooth (*a*)	61.2	179	.91	62.1	143.4	93.5	91.
57	" " "	50.3	162	.74	51.0	117.8	76.	74.
58	" " "	40.2	146	.60	40.8	94.2	61.5	59.
59	" " "	25.4	115	.37	25.8	59.6	43.	41.5
60	1-inch smooth (*c*)	61.3	234	1.59	62.9	145.2	91.5	88.
61	" " "	55.2	219	1.39	56.6	130.7	84.	82.5
62	" " "	50.4	210	1.27	51.7	119.4	76.5	74.25
63	" " "	40.1	187	1.01	41.1	94.9	65.5	63.5
64	" " "	30.1	161	.74	30.8	71.1	50.	48.5
65	1⅛-inches smooth (*B*)	50.1	267	2.03	52.1	120.3	81.	79.
66	" " "	55.8	281	2.26	58.1	134.2	90.	87.5
67	" " "	40.2	239	1.64	41.8	96.5	67.	65.5
68	" " "	30.0	206	1.23	31.2	72.0	51.	50.
69	" " "	25.0	187	1.01	26.0	60.0	41.5	40.
70	1¼-inches smooth (*e*)	50.3	331	3.20	53.5	123.5	84.	82.
71	" " "	40.0	296	2.51	42.5	98.1	67.5	66.
72	1⅜-inches smooth (*f*)	46.6	384	4.26	50.9	117.5	81.	80.
73	" " "	40.0	357	3.66	43.7	100.9	69.	67.
74	" " "	35.0	334	3.24	38.2	88.2	61.5	60.3
75	" " "	30.1	311	2.80	32.9	75.9	52.4	51.
76	" " "	25.0	283	2.26	27.3	63.0	43.5	42.5

In all experiments in this table water was supplied from city reservoir.

TABLE No. 11—(*Continued*).

Elevation of Jet above End of Nozzle.		Observed Horizontal Distance North from End of Nozzle.		Remarks.
Extreme Limit of Good Fire Stream.	Extreme Limit of Fair Fire Stream.	Of Summit of Jet.	Of Middle of Jet where striking ground.	In all these experiments noted below, the regular 30-inch Morse play-pipe was used and was fed by 50 feet of solid rubber hose. The hose near play-pipe was laid on a flat, inclined table which kept it in a plane curve and was confined between circular blocks which held it in a curve of 3 feet radius and of 90 degrees arc. Up stream from this point hose was straight for 10 feet and thence led to hydrant in a loop curved nowhere with less than 4 or 5 feet radius.
77	82	88	*	
63	66	71		
45	55	62		
36	39	45		
75	80	85	120	
72	77	78		
60	64	75		
55	58	70		
42	48	55		
69	75	92	126	Excellent experiment. No wind. Mean of several independent trials.
73	79	89	120	Occasional faint puffs of wind, but not enough, I think, to affect jets. Very little difference in character of stream under the different pressures. Stream if anything of better character under the high than the low pressures.
50	58	70	107	
45	48	57	90	
37	40	43	78	
75	80	88	.....	Both these are excellent experiments. Wind very faint. Drops at summit, ½-inch diameter.
57	63	70	.....	
63	72	87	Center, 128 Extreme, 135	No wind.
58	65	74	Center, 118 Extreme, 123	
50	55	65	105	
46	50	56	100	
35	40	46	86	

* Values in this column not sharply defined.

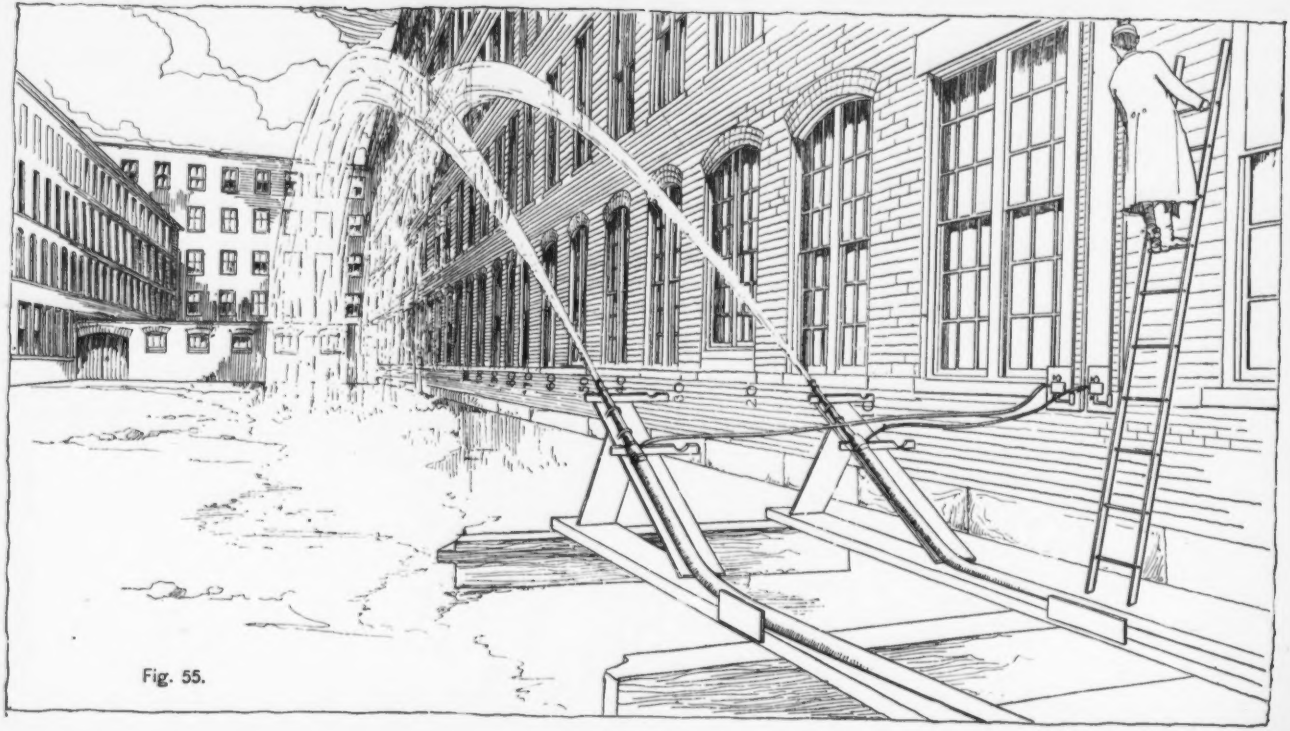


Fig. 55.

Jets at 32 Degrees Elevation.

These experiments were intended to show the greatest horizontal distance that jet could attain. Their site is shown in Fig. 55. It will be noted that the site was well sheltered from currents of air, but care was taken to record no experiments here when any breeze was perceptible other than the slight air current caused by the jet itself.

The range of pressure was carried up beyond limits of ordinary practical use, and I consider that this set of experiments is very satisfactory.

Distances east from end of nozzle were measured off by a steel tape and conspicuously marked on the adjacent wall, and as the nozzles were set just at level of the window sills and as windows happened to be built with 10-foot bays and stories just 15 feet high, the mill itself furnished a convenient measuring scale, and its windows furnished very convenient points for observation. The heights were, however, determined with much less exactness, proportionally, than for experiments at Fig. 54, the main attention being here given to the distance. It will be seen that the nozzle supports were adjustable to various angles of elevation. Several preliminary experiments were made with 50 pounds pressure, to determine angle of elevation which would give the maximum horizontal distance. Thirty-two degrees was the elevation which appeared to do this, and was adopted in the experiments as being a fair value within the range of pressures adapted for ordinary fire streams; but as a degree or two made but little difference in this distance, it cannot be stated certainly whether 30 or 34 degrees might not have served equally well.

As there was a slight deflection of support for nozzle under the recoil from the jet, this angle of elevation was determined with less exactness than for jets shown in Fig. 54, and may be 1 degree in error. Care was taken, however, that when a comparison between two jets was made the angles of elevation should be precisely the same.

Certain other experiments at 15 pounds pressure showed that this low pressure, 35 to 40 degrees elevation, enabled stream to reach about 5 per cent. further than 32 degrees elevation. And at from 5 to 10 pounds pressure the maximum horizontal distance was found to be attained when elevation approached 45 degrees.

The extreme end of jet was made up of a mere rain of scattering drops and was less sharply defined than in the vertical jets; but as I was able to stand close beside it, a fair average could be taken, and even at the highest pressures I think the recorded maximum distance could seldom, if ever, have been more than 5 feet in error. The main body

TABLE No. 12.

EXPERIMENTS ON "HORIZONTAL" JETS. ELEVATION, 32 DEGREES.

November 9th, 1888. Temperature of air, 55 degrees. Temperature of water, 49 degrees. Water supplied by rotary fire pump.

No. of Experiment.	Size and Kind of Nozzle.	Actual Pressure above Orifice, Shown by Gauge Connected at Base of Play-pipe.	Computed Discharge of Nozzle. Gallons per Minute.	Correction for Velocity Past Gauge.	Computed Static Pressure above Orifice. Pounds per Square Inch.	Computed Static Pressure above Orifice. Feet.	Observed Horizontal Distance from end of Nozzle reached by Jet.				
							At Level of Orifice.			At Summit.	Extreme Limit of Good Fire Stream.*
							Average of Extreme Drops.	Average of Main Body.	Distance Reached by three-fourths of Water.		
77	¼-inch Smooth Cone (*a*)	99.7	168	0.81	100.6	232.3	167.	155	140	130	70
78	¼ " " "	75.4	146	0.61	76.1	175.7	150.	140	120	100	57
79	¼ " " "	51.8	119	0.39	52.2	120.5	127.	120	100	80	50
80	¼ " " "	31.1	92	.24	31.3	72.3	98.	95	87	57	38
81	1-inch Smooth Cone (*c*)	106.1	308	2.75	108.9	251.4	205.	195	165	150	88
82	1 " " "	79.3	265	2.00	81.3	187.7	188.	175	150	125	78
83	1 " " "	47.3	203	1.08	48.4	111.8	147.	140	120	87	57
84	1 " " "	30.4	162	.75	31.2	72.0	108.	105	.....	59	47
85	1½-inch Smooth.....(*B*)	101.0	380	4.18	105.2	242.9	230.	215	175	150	90
86	1½ " ..... "	88.0	354	3.61	91.6	211.5	210.	197	.....	150	80
87	1½ " ..... "	75.6	328	3.13	78.7	181.7	197.	190	150	127	73
88	1½ " ..... "	50.4	268	2.03	52.4	121.0	165.	155	.....	95	65
89	1½ " ..... "	50.0	267	2.02	52.	120.0	164.	155	.....	95	65
90	1½-inch Smooth Cone (*A*)	20.0	169	.81	20.8	48.	.....	.....	.....	.....	43
91	1½ " " "	15.3	99	.61	15.9	36.7	60.	59	.....	32	40
92	1½ " " "	9.7	40	.40	10.1	23.3	36.5	36	.....	18	20
93	1½-inch Smooth Cone (*c*)	94.3	454	5.95	100.3	231.6	230.	210	180	155	95
94	1½ " " "	75.8	406	4.80	80.6	186.1	208.	200	160	137	80
95	1½ " " "	49.7	330	3.16	52.9	122.1	169.	157	138	98	75
96	1½ " " "	35.9	281	2.25	38.2	88.2	137.	130	120	70	65

In all these experiments jets were sheltered by mill wall and there was no wind whatever blowing, except some motion of air caused by jet itself.

In all experiments of November 9th water was supplied by the mill fire pump. Experiments 90, 91, 92 were made upon February 21, 1889, measuring pressure by Bourdon gauge.

*Since constructing the jet diagram, I have been led to think that perhaps on this day I was uncommonly critical, and thus rated distance to which stream could be classed as a "good fire stream" a few per cent. too low.

TABLE No. 12—(*Continued*).

Observed Elevation of Jet above End of Nozzle.				Remarks.
Extreme Limit of Fair Fire Stream.	At Summit.	At Limit of Good Fire Stream.	At Limit of Fair Fire Stream.	
77	52			
70	40	.....	.....	All rain beyond 100 feet.
60	31	.....	.....	All rain beyond 85 feet.
45	20	.....	.....	Too small and feeble for a first-class stream.
98	65	.....	.....	All is a rain beyond 170 feet.
90	48	.....	.....	Only rain beyond 130 feet.
75	45			
55	20	19.5		
105	63	50.	.....	Beyond distance 180 feet this is only a heavy rain. At 70 feet distance stream all
100	55	41.	.....	[goes within circle of 1 foot diameter.
95	48	40.		
80	34	29.5		
80	33	30.5	.....	Beyond 155 feet distance jet became only a heavy rain.
.....	.....	.....	.....	At 36 and 40 degrees elevation stream goes 3 feet farther.
45	.....	.....	.....	Stream is tolerably compact to end—would do fair execution in second story of a cottage house.
.....	.....	.....	.....	This at 45 degrees elevation, since that was found to throw farthest.
108	65	48.	.....	Stream all rain beyond 180 feet.
100	50	.....	.....	Stream mostly rain beyond 155 feet.
85	33	32.	.....	" " 130 "
70	24	23.		

was also not sharply defined. As considerable variations appear on all the plotted sheets of jet experiments, it is but fair to state that an earnest effort was made to have the successive observations independent of one another, and with this in view the writer frequently called an assistant to make an independent record of his own opinion of the proper values for distance, etc. In other words, it was intended that the record should fairly represent the indefiniteness existing in the observation.

In all these jet experiments, at whatever angle, one assistant manipulated the hydrant-gate, another observed the mercury gauge continuously, and another generally assisted by observing jet from a different point of view from the station of the writer. Care was taken that water, after opening the hydrant-gate, should get into a condition of steady flow before the observations were begun.

The observations of Table No. 9, on extreme height of vertical jets, were plotted on cross-section paper to the scale of one centimeter, = 2 feet and = 2 pounds. A small scale photographic reproduction of this plotting is shown in Fig. 56, and on the same sheet in Fig. 56*b* are shown the heights attained by jets at 75 degrees elevation.

It will be seen by table that no experiments on jets exactly vertical were obtained with higher pressure than 60.7 pounds. Experiments on vertical jet from each size of nozzle would have been made at pressures ranging up to 100 pounds, but for failure to find an opportunity when the air was still enough to make observations of any real value. The curves for mean values of height attained by extreme drops under pressures from 60 to 110 pounds were therefore projected by the aid of experiments upon the 75-degree jet plus a percentage derived from a comparison of the vertical with the 75-degree jets at from 40 to 50 pounds pressure.

Accuracy of Mean Curves for Height and Distance of Jets.

I consider that we can prudently rely on the mean curves of Figs. 56 and 57 being not more than two or possibly three per cent. in error in their definition of the extreme height and distance to which a stream will rise or reach in still air under a given pressure. It will be noted that the completeness and general agreement of observations is better for horizontal distance than for vertical height.

The proper location for these curves was studied with much care, taking the four sets with the different angles of elevation together, and making use of various little auxiliary plottings and computations.

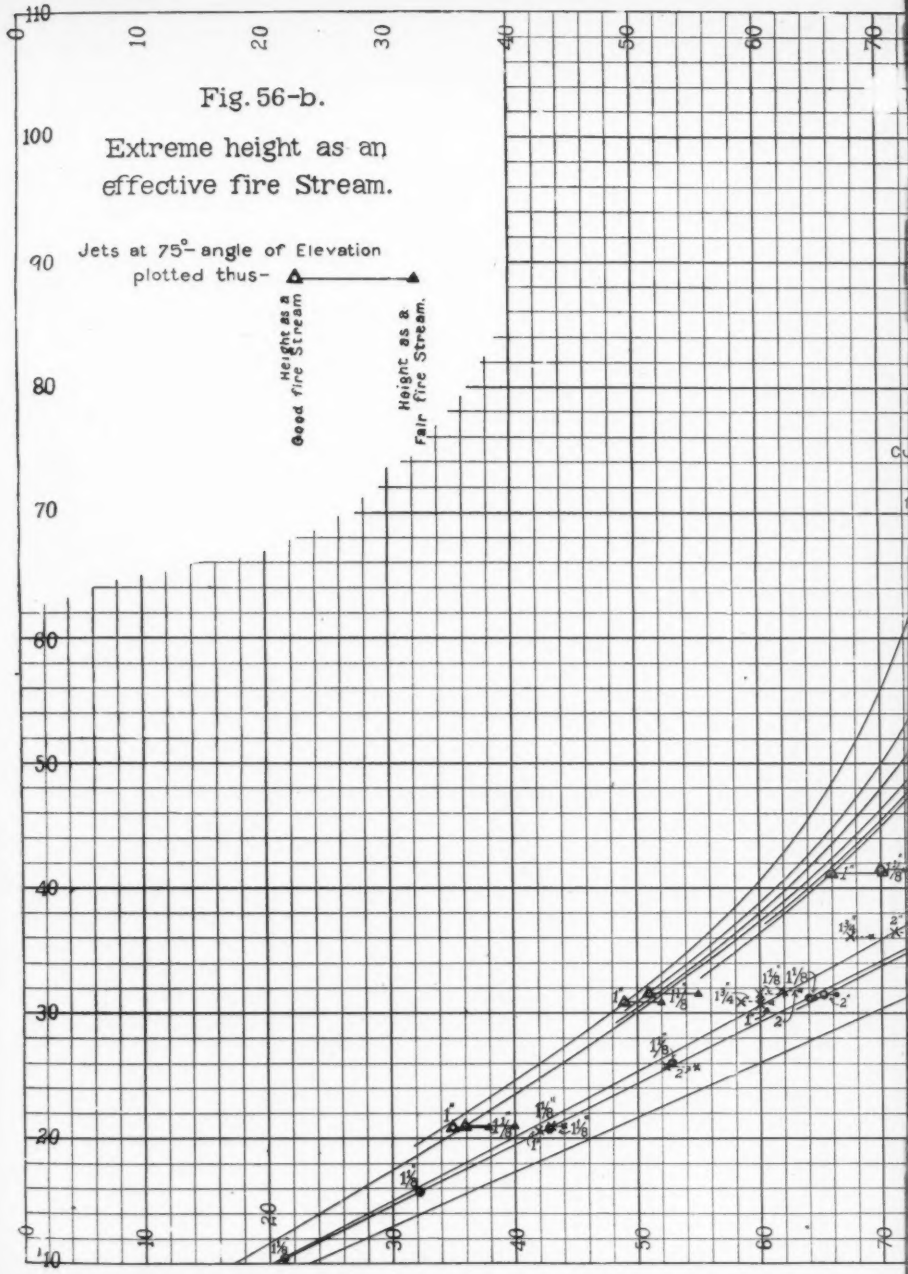
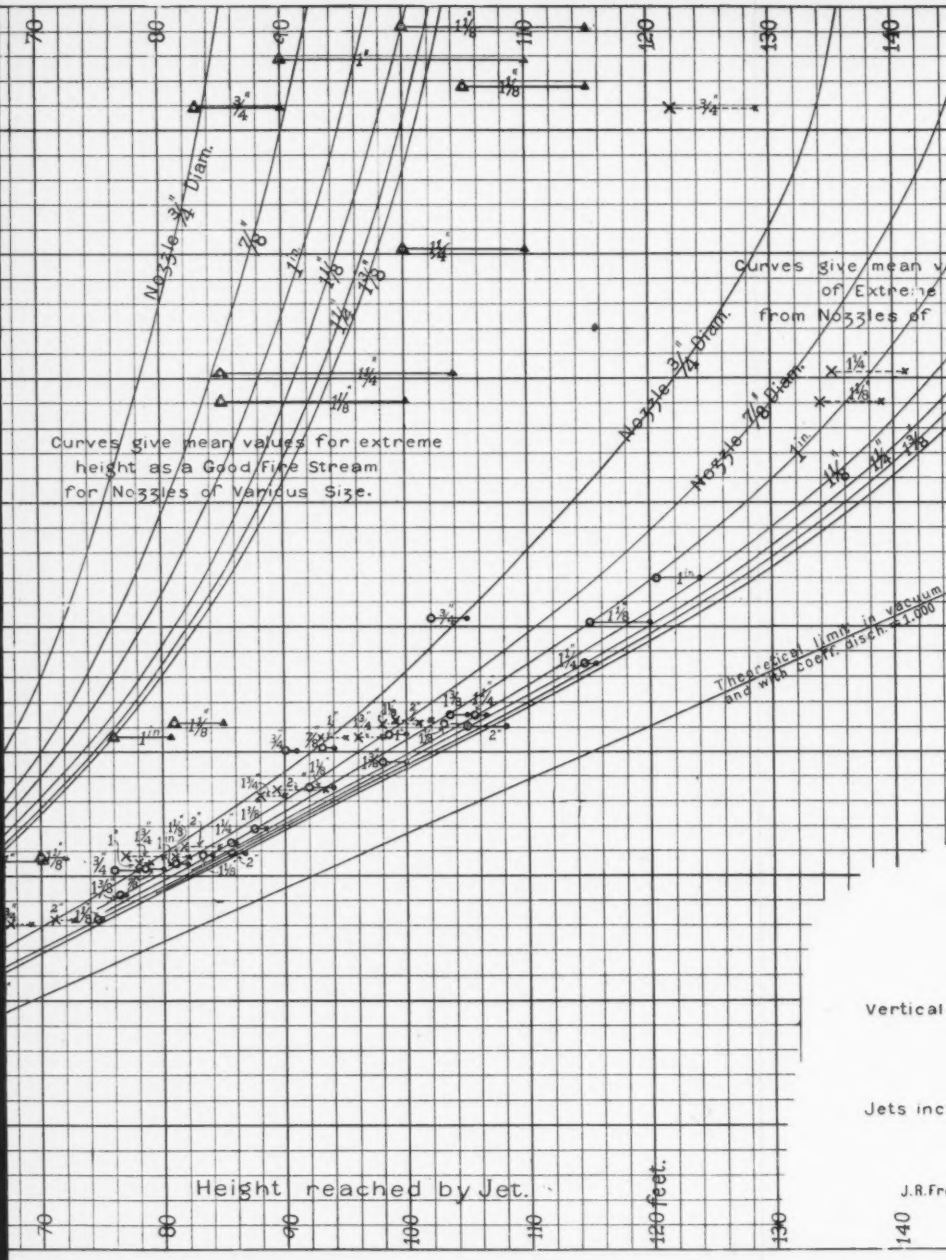


Fig. 56-b.
Extreme height as an effective fire Stream.
Jets at 75°- angle of Elevation plotted thus-
Height as a Good fire Stream
Height as a Fair fire Stream.
0
10
20
30
40
50
60
70
80
90
100
110


Nozzle 3/4" Diam.
7/8"
1"
1 1/8"
1 1/4"
1 1/2"
1 3/4"
2"
Curves give mean values for extreme height as a Good Fire Stream for Nozzles of Various Size.
Nozzle 3/4" Diam.
Nozzle 7/8" Diam.
Curves give mean v
of Extreme
from Nozzles of
Theoretical limit in vacuum and with coeff. disch. = 1.000
Vertical
Jets inc
J.R.Fr
Height reached by Jet.
Feet.
70
80
90
100
110
120
130
140

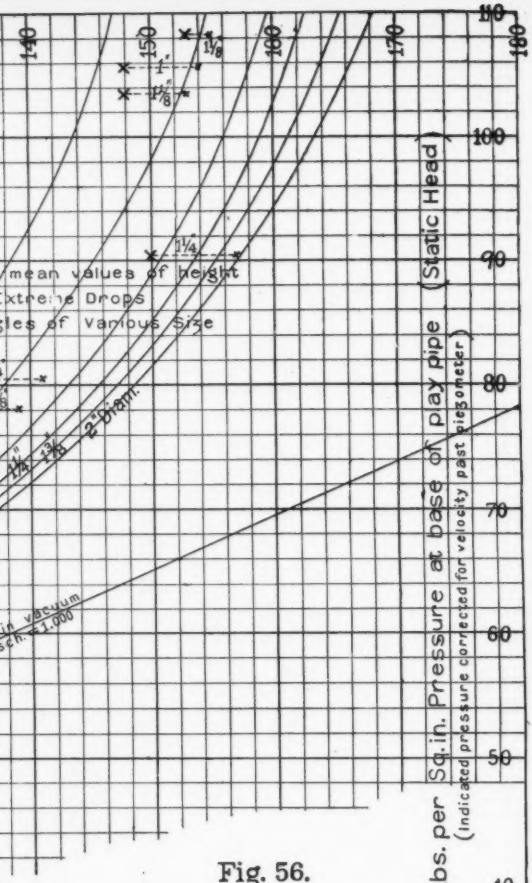


Fig. 56.

Extreme Height of Jets.

See Tables 9 and 10.

Vertical Jets plotted thus

Jets inclined at 75°-Elevation plotted thus

J.R.Freeman – Hydraulics of Fire Streams.

F.M.H. Del.

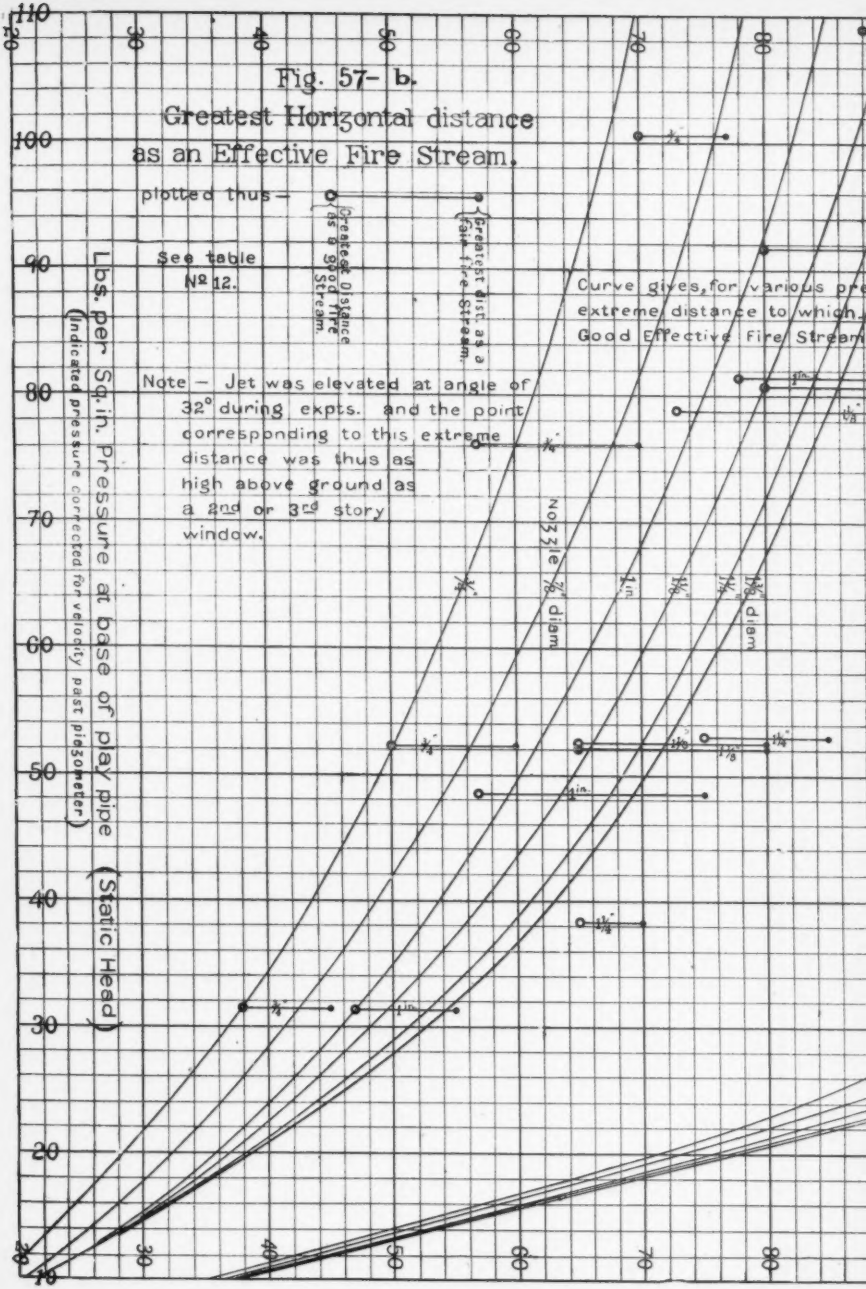
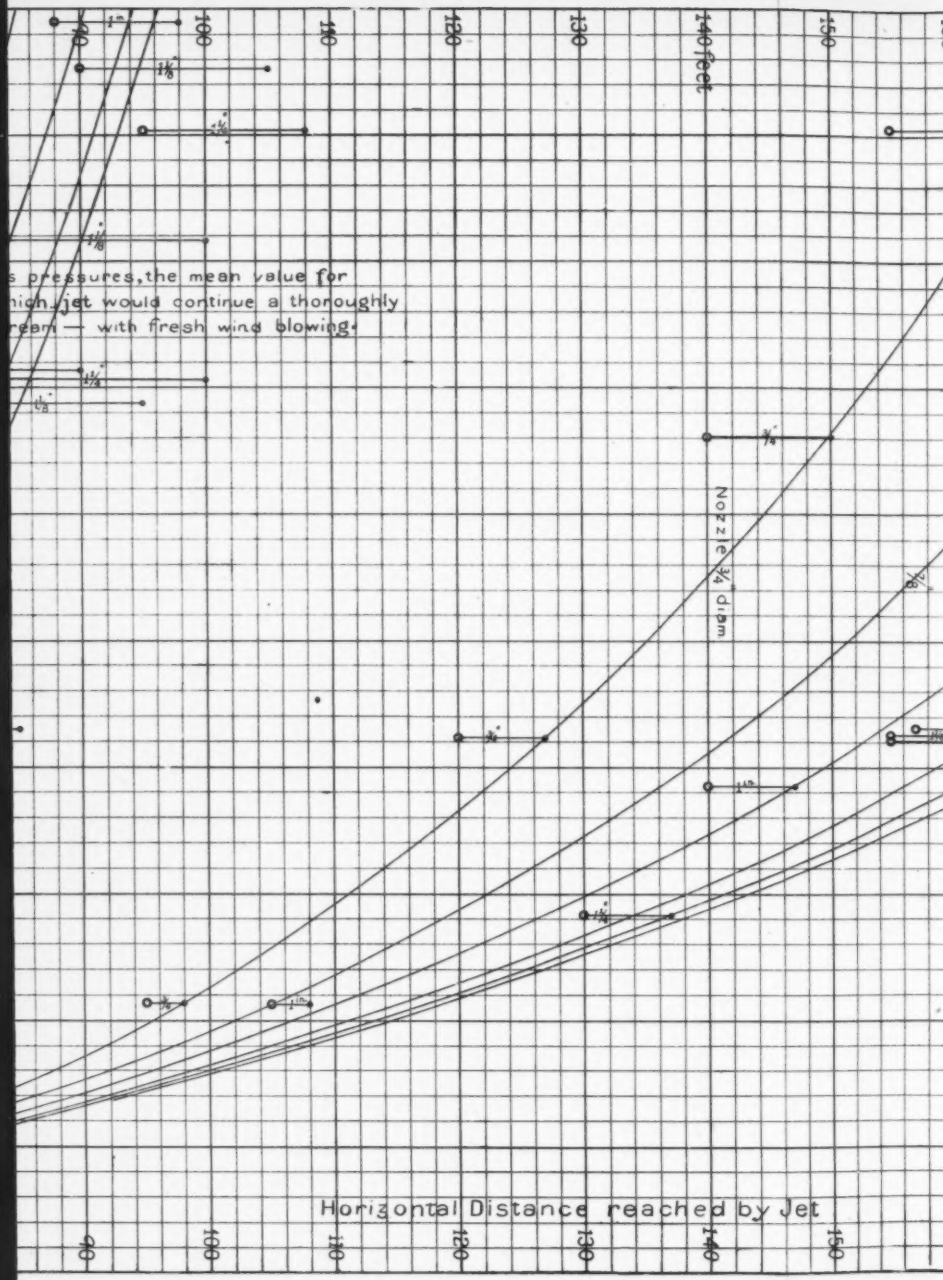


Fig. 57- b.
Greatest Horizontal distance
as an Effective Fire Stream.
plotted thus –
Greatest Distance as a Good Stream.
Greatest dist. as a Fair Fire Stream.
See table Nº 12.
Note – Jet was elevated at angle of 32° during expts. and the point corresponding to this extreme distance was thus as high above ground as a 2nd or 3rd story window.
Curve gives, for various pre
extreme distance to which
Good Effective Fire Stream
Nozzle 7/8" diam
1in.
1 1/8" diam
1 1/4" diam
Lbs. per Sq. in. Pressure at base of play pipe (Static Head)
(Indicated pressure corrected for velocity past pitsometer)


s pressures, the mean value for
hich jet would continue a thoroughly
ream — with fresh wind blowing.
Nozzle ¾ diam
Horizontal Distance reached by Jet
feet

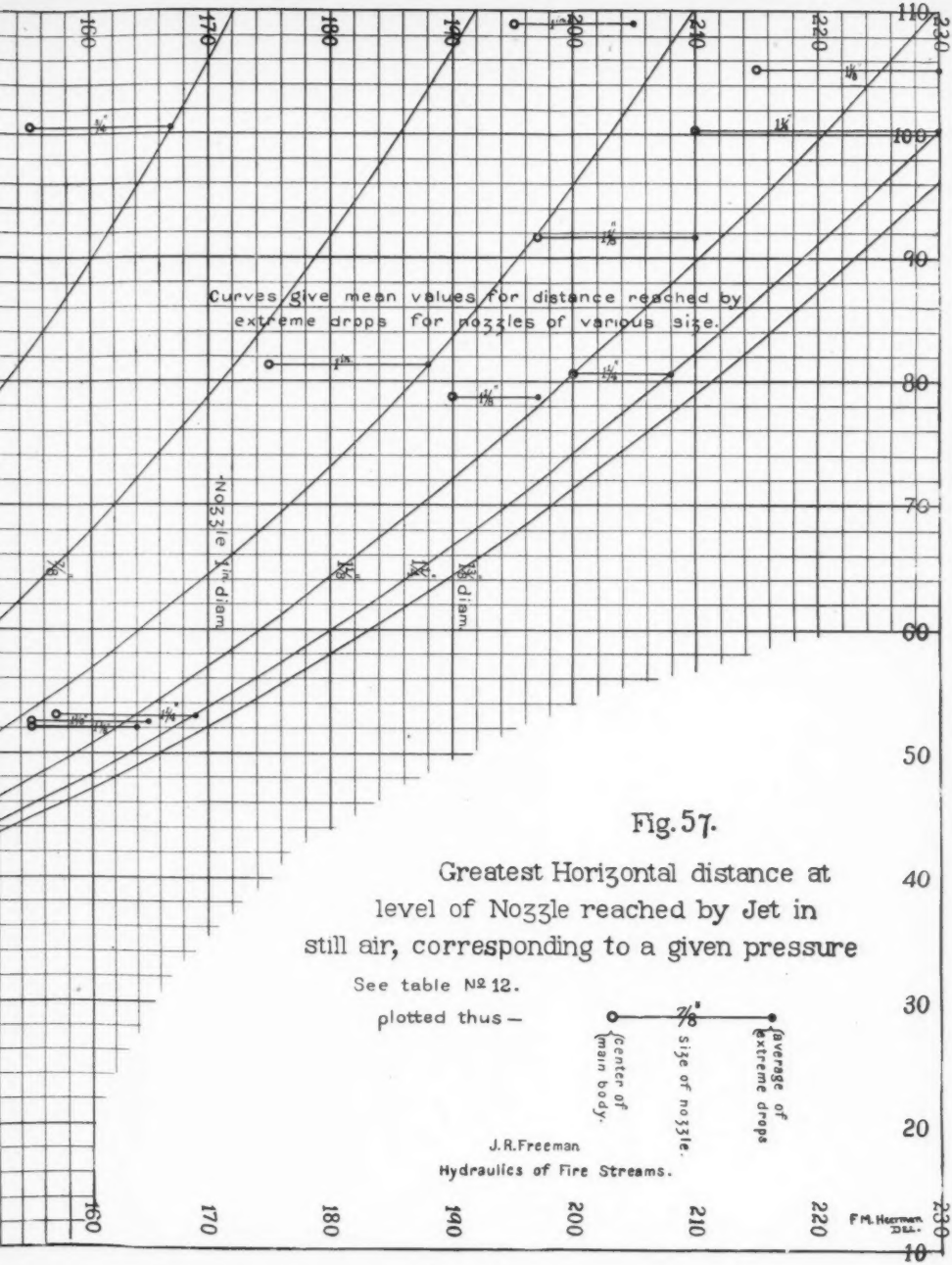


Fig. 57.

Greatest Horizontal distance at level of Nozzle reached by Jet in still air, corresponding to a given pressure

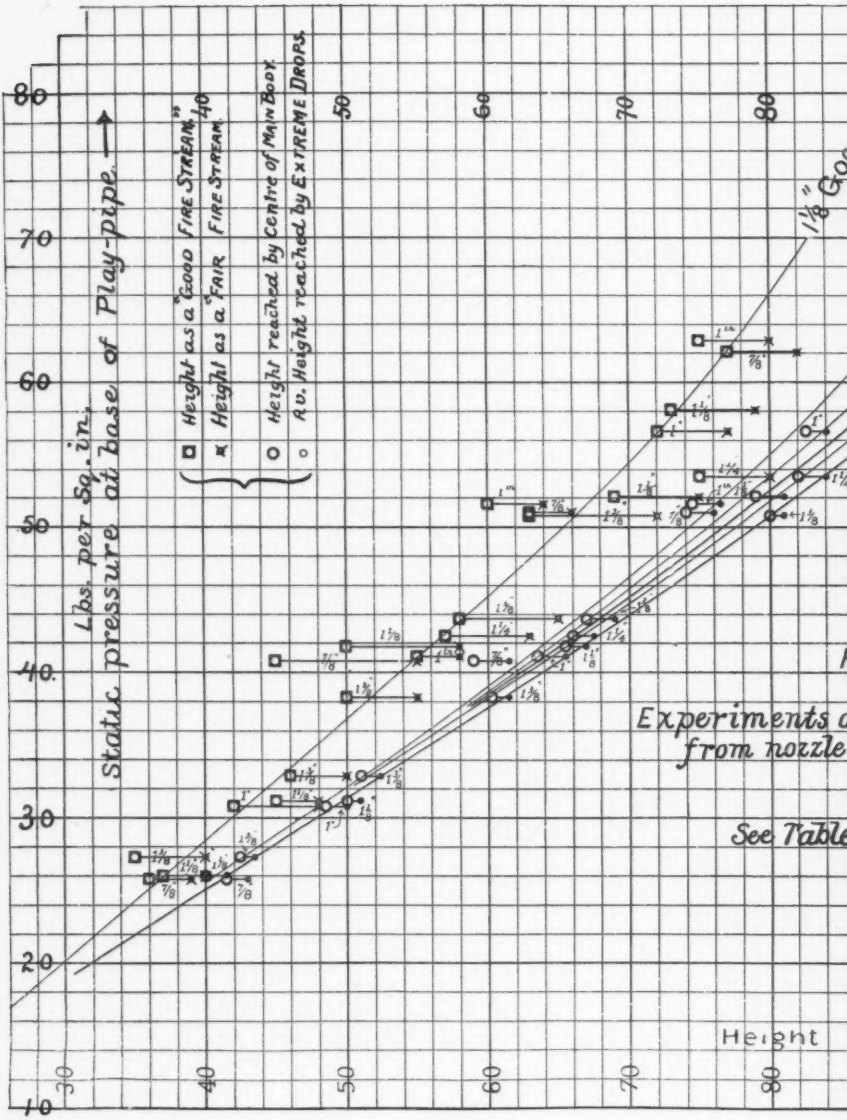
See table Nº 12.

plotted thus —

J. R. Freeman

Hydraulics of Fire Streams.

F M. Heerman Del.


Lbs. per Sq. in.
Static pressure at base of Play-pipe.
Height as a "Good Fire Stream"
Height as a "Fair Fire Stream"
Height reached by Centre of Main Body
Av. Height reached by Extreme Drops.
1/8" Go
Experiments o
from nozzle
See Table
Height

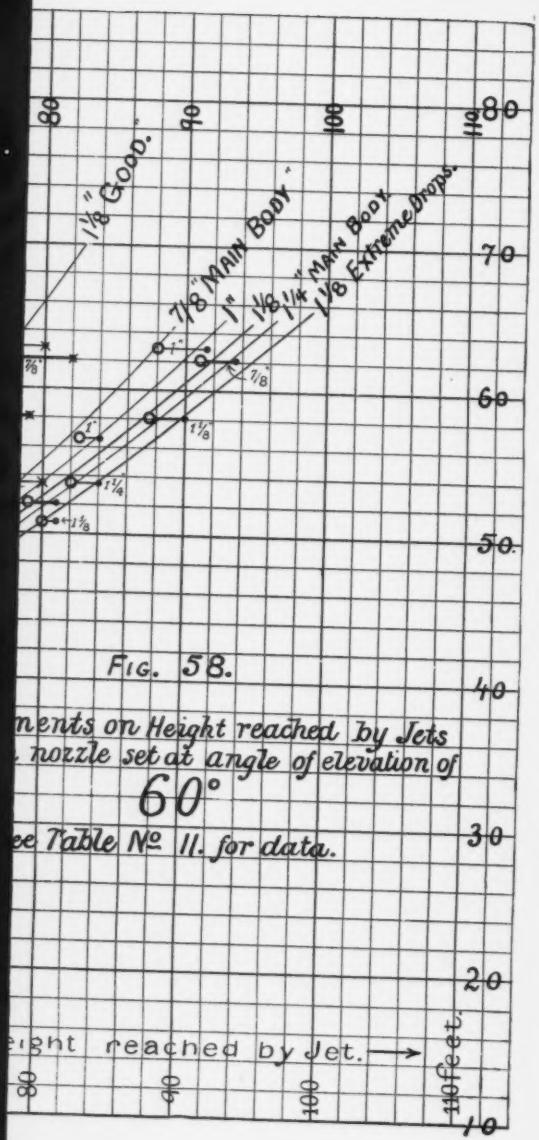


FIG. 58.

ments on Height reached by Jets
nozzle set at angle of elevation of

60°

ee Table № 11. for data.

In some cases one observation was given slightly less weight than another, but only when justified by recollection of some circumstance unfavorable to the highest accuracy.

An earnest effort was made to keep the curves close to the plotted observations, rather than to follow any particular algebraic law.

The full records of the observations have been given, to enable any investigator to judge of the liability to error of these curves, to draw new curves or to arrange an algebraic expression for the law.

It may not be amiss to say that for problems of this nature I believe a large scale plotting and the method of average judgment to be preferable to the "method of least squares." It so happened that I did not attempt to state the result in algebraic form until after the practical tables were computed and Figs. 56, 57 and 58 engraved. Any formula for this must be almost purely empirical and an empirical curve was deemed as good as an empirical formula for the preparation of the practical fire stream tables which was the main purpose in view. In cases like this a curve is more convenient than a formula for most practical uses, and has the advantage of being less likely to be used far beyond the limits of the experiments from which it was derived.

In connection with limiting the application of an empirical formula to the range of the experiments from which it was derived we may again refer to the Box formula for jets. Mr. Box presents a formula whose curve coincides very well with the few experiments at hand, and then guided but by a single experiment on a 1-inch jet proceeds far beyond most of the experiments into a generalization from the mathematical form of this curve, that it follows for each size of nozzle there is a pressure producing a maximum height of jet, and that to increase the pressure beyond this point will actually diminish the height of jet. Now this may very likely be true, or possibly for a jet of given size the height may remain nearly stationary above a certain pressure, but as yet no really decisive experiments are on record. If, as is not unreasonable to suppose, there is a slight decrease of height for extremely high pressures, it probably follows an entirely different law from the ascending curve.

It will be seen that the range of the experiments includes all sizes commonly used for fire streams, and that the pressures at base of play-pipe were carried up considerably beyond those with which firemen can work with any ordinary appliances.

The curves of Figs. 56 and 57 were used in the construction of the practical tables at the end of this paper.

To express algebraically with great accuracy the extreme height to which a jet of given diameter will rise under a given head requires a formula which, so far as I have been able to devise it, is inconveniently complicated for ordinary use.

As an approximate formula, the following will serve very well, and within the range of fire streams, namely, for diameters of from $\frac{3}{4}$ inch to $1\frac{3}{4}$ inches and pressures of not more than 80 pounds, its use will not lead to an error of more than 3 or 4 per cent.* Practically this is near enough for almost any purpose, inasmuch as even a faint wind will lessen the height to an extent greater than the error in this formula:

Let J = extreme height in feet to which the average extreme drops of a vertical jet will rise in still air.

h = static head of water in feet acting at base of play-pipe.

d_1 = diameter of jet close to nozzle in inches. (For smooth nozzles this is same as diameter of orifice. For ring nozzles take d_1 as 86 per cent. of diameter of orifice.)

Then $J = h - .00135 \frac{h^2}{d_1}$.

This is substantially the same as the formula used by Box, but expressed in more convenient form and with the constant modified to fit my experimental results.

For values of d_1, larger than 2 inches, use 2, until further experiments, since the plotted curves indicate that for sizes larger than this the effect of diameter of jet upon its height is small.

---

* For pressures of from 40 to 70 pounds, and diameters from $\frac{3}{4}$ up to $1\frac{3}{4}$ inches, this formula agrees remarkably well with the experiments. For diameters larger than $1\frac{3}{4}$ inches the diameter has less influence on height to which the water will rise than the formula indicates; and, indeed, it would appear that after a diameter of 2 inches was reached, a further increase of size would have but little influence on height, while pressure remained the same.

When pressures become greater than 70 pounds, or 150 feet, the loss in height of jet by resistance of air increases apparently at a more rapid rate than the formula implies, or varies as a power of h somewhat higher than the square. Until we have more data on jets of 2 or more inches diameter and at pressures of 100 pounds and upward, it is, perhaps, best not to attempt to devise an extremely accurate general formula. Meanwhile the above formula, the plotted curves of Fig. 56, or the table in the appendix, will satisfy almost any practical purpose.

Experiments to Determine Best Form of Nozzle.

A leading object of these experiments was to determine the best form of nozzle and play-pipe for practical use, or to find out what form would, for a given pressure, project a given number of gallons of water per minute to the greatest height or distance, and with the least loss by the detaching of drops or spray on the way, thus delivering the water in as solid a body as possible, at the greatest possible distance.

At the beginning of the experiments there was no thought of trying half so many different styles of nozzle; but as the experiments went on, various lines of inquiry were prompted by the facts developed, and new nozzles were constructed or additional styles found in practical use were secured for experiment; for in matters like this one seems never to get to the end. Had time afforded, still other styles would have been constructed and experimented upon, and the experiment would have been made of directly measuring the number of gallons thrown into an opening of certain size, located at a given distance from nozzle near end of jet, thus obtaining a definite measure of the amount of water detached from the main stream and lost by spray with the different styles of nozzle. However, the range of the experiments actually made covers the subject well enough for all present practical purposes. It is believed that the conditions for accurate comparison were much superior to those generally available, and therefore the results are given with considerable detail, in order that future seekers for the "perfect nozzle" may save time by avoiding paths already pursued.

In one way the results of these comparisons were disappointing to the writer, for at the beginning he did not expect to find the plain cone superior in projecting power to all other forms tried. It was hoped that some form or modification would be found from which the jet would issue in a clear, transparent, polished stream, with a clean, glassy surface, and with little spraying for the first quarter of its course.

Out of the about forty different nozzles tested, there was not one which threw such a stream, and though the writer has had occasion to critically examine the streams from many other nozzles, he has not yet seen one which, under pressures of 30 pounds or upward, gave this transparent and undisturbed appearance, similar to that found, for instance, in the stream over a well constructed weir.

For pressures of 5 or perhaps even 10 pounds a smooth, transparent stream can be obtained; but with a good working pressure like 40

pounds there was always found even only an inch away from the orifice a "ground glass appearance" on surface of jet.

And a careful and minute examination showed that even at an inch distance from orifice of the best nozzles or within about one-thousandth part of a second of time after issuing into free air, minute drops were beginning to tear themselves away from the main body, this being induced, no doubt, by the retardation due to walls of orifice, and to the consequent great difference in velocities between particles in the different layers near outside of jet.

The conclusion derived from all these comparisons, made, many of them, under conditions where 6 inches difference in heights of jet for the same pressure could be readily distinguished, and with accelerations varying from a uniform acceleration nozzle (E) to a sharply contracted ring nozzle (k), was:

First.—That form of convergence of nozzle makes much less difference in jet than had been previously supposed.

That if shape be such that eddies or tendencies toward eddies or unsymmetrical currents are not induced, then it makes but very little, if any, difference in character of jet, whether the longitudinal section of nozzle be a straight taper, or a curve giving uniform acceleration in a given time, as proposed by Mr. Nagle and some others, or a curve giving uniform increase of velocity in a given distance, as proposed by Captain Shaw, or any smooth nondescript curve.

Second.—The plain conical nozzle B, shown in Fig. 16, in connection with the play-pipe shown in Fig. 13, gave a jet which was, on the whole, slightly superior to any other form tried. And the nozzle shown in Fig. 7, designed since the experiments as a standard form easily manufactured, is presented with the belief that it is as good a form for practical use as can be constructed.

There are many fancy "nozzles" to be found, the possessors of which claim for them wonderful merit, and nozzles are frequently brought forth at firemen's musters of which the form is a most jealously guarded secret; but I am disposed to regard these special merits as fanciful rather than actual, and to think that by giving great care to accurate form and high polish of a nozzle like that shown in Fig. 7 equally as good results can be attained.

Third.—Ring nozzles were found to possess no advantage whatever over smooth nozzles, but proved very slightly inferior in projecting

power and gave a greater amount of spraying; and though this difference was so small as to be only barely perceptible and of almost no practical moment, yet the use of ring nozzles should be discouraged as tending to deceive, since their only advantage is to make a show of playing a larger stream than is the fact.

COMPARISON OF EFFICIENCY OF NOZZLES AND PLAY-PIPES.—ROTARY MOTION, OR TWISTING OF CURRENT AT NOZZLE.—(See drawings of nozzles on pages 318 to 325.)

For a fair and very accurate comparison of two play-pipes it is necessary that the hose for at least 5 to 8 feet back from play-pipe lie in a plane. There may be a curve close to play-pipe; but it must be a plane curve, not warped or twisted or cork-screw-like in the slightest degree. For it seems that this warped, cork-screw-like or spiral approach tends to produce a rotary motion within the play-pipe; and as the water progresses through the play-pipe and nozzle, it being confined within a channel of diminishing diameter, the angular velocity of rotation of the water becomes greater as it passes along (like the water in the vortex of a whirlpool), and on issuing into free air this rotary motion, by the centrifugal force generated, acts to cause more scattering of the jet.

Comparison No. 1.—That this is the case was indicated by simultaneous observations as shown in Fig. 54, with two play-pipes of the same length fitted with nozzles of same size (1¼ inch smooth) placed side by side, elevated at 60 degrees, each fed by 50-foot pieces of hose of same kind and size (2½-inch solid rubber), with pressure at base of nozzle identical within $\frac{1}{10}$ pound. The only difference in the conditions affecting the jets was that while hose to one lay in plane curve of 90 degrees arc and 3 feet radius, the similar curve in hose to the other nozzle was about 2 inches "winding," or out of plane at center of arc, and thus was a slightly warped or helical curve. It was found, and confirmed by reversing position of nozzles while position of hose remained unchanged, that height and distance reached by the latter jet, in which the conditions favored a slight twisting of currents, was 3 to 5 per cent. less than that attained by the first mentioned jet, which had that part of the hose close to its nozzle lying in a plane curve.

This twisting of jet has been noted by many practical men, and its effect sometimes, I think, overestimated. Several patents have been taken out for devices for preventing the twisting of current. I con-

structed, especially for these experiments, the play-pipe shown in Fig. 18, with the expectation that these blades, which projected in far enough so that more than half the whole body of water lay exterior to a cylinder containing their inner edges, would practically control the twisting motion of jet, and that it would present the advantage over nozzle shown in Fig. 24 of less surface for internal friction and less liability to obstruction by a stone or other foreign substance passing through pipe.

It may be of interest to mention that it was learned subsequently (see Bowie's "Hydraulic Mining," page 50, also page 182) that this device of straight internal blades parallel to axis, and called a "Rifle," was patented twenty-five years ago and much used in the monitor nozzles for the hydraulic mines of California, and proved of very material advantage in removing the twist induced by the swivel joint at base of play-pipe. The term rifle blades is to some extent a misnomer, since the blades are put in with an entire absence of that twist, on which the advantage of rifling for a gun depends.

I was disappointed in the results attained, for it was found that these rifle blades, shown in Fig. 18, were not fully effective for preventing this rotary motion, even where the curve of hose was so slightly winding, as noted above, and moreover, it was difficult and expensive to insert blades with proper straightness in pipe of size of fireman's play-pipe.

Comparison No. 3.—When both lines of hose were laid in plane curves, and all arranged as shown in Fig. 54, no difference whatever was perceptible between stream from the "rifle barrel" and stream from the ordinary pipe of same size without the rifle blades; both being tried simultaneously side by side at same elevation, with pressure identical, and under conditions where a difference of one per cent. would have been readily noticeable.

The Silsby Manufacturing Company, well known as enterprising builders of steam fire engines, have introduced a special play-pipe of the form shown in Fig. 24, containing internal diaphragms for straightening the current. One of these pipes, with the two nozzles as shown, was kindly loaned me by the Messrs. Silsby. I tested it with especial care in the manner shown in Fig. 54 and again on another day in the manner shown in Fig. 55, and repeated these tests at a demonstration given in presence of our corps of inspectors and others.

Comparison No. 4.—In all cases when the hose near base of play-pipe lay in a plain curve, as shown in the figures, these experiments established with certainty the fact that the jet from this play-pipe with the internal partitions was in no way superior to that from the ordinary play-pipe shown in Fig. 13, but averaged not reaching so far by from 1 to 3 per cent. for the same pressure.

Comparison No. 5.—The Silsby pipes proved superior, however, when the lines of hose near the bases of the two play-pipes were lifted out from the blocks which held hose in a plane curve, and the hose was thus brought into a cork-screw-like form. The jet from the ordinary pipe without partitions was made less perfect by the rotary or twisting motion thus induced in the hose, while the jet from the Silsby pipe held its original character. For cases where this irregularity of curve of hose was made as great as would probably occur in ordinary practice, it was found that the spraying of jet within 25 feet of the Silsby nozzle was very noticeably less than from the other, and that the distance reached by main body of jet from Silsby nozzle was, say, 2 to 4 per cent. greater than distance reached by main body of jet from the plain nozzle. My conclusions regarding the use of "Rifle blades" or internal partitions on play-pipes of size adapted for 2½-inch hose is, that they are not advisable.

Rotary Motion and Disturbed Flow in Siamese Nozzles.

With the ordinary Siamese, by which two, three or even four hose streams are united into one at base of play-pipe, or united at a point within 25 feet of it, some arrangement similar to the rifle blades already mentioned seems absolutely necessary to the obtaining of a good clean jet. This is especially true of an arrangement like that shown in Figs. 43 and 44, where the union of the several lines of hose occurs close to base of play-pipe. The play-pipe for this was so made that the rifle blades shown in Fig. 45 could be removed.

Comparison No. 6.—The removal of these blades and partitions was tried repeatedly, and the effect on jet was very marked. When blades were removed, the twist of the jet as it issued was very plainly noticeable, and judging as closely as possible by the eye alone, it appeared that for a pressure of 50 pounds at Siamese, the spraying was fully 25 or perhaps 33 per cent. more when partitions were removed than when they were in.

Comparison No. 7.—A careful comparison between the merits of the partitions reaching to the center, and the blades reaching half way to center, both shown in Fig. 45, showed certainly that the partitions gave the better stream. That is, the stream was more solid, with fewer drops detached in the first half or two-thirds of its course. It was found, moreover, that it was much more difficult to construct the pipe with blades of proper straightness than to construct the partitions and keep their surfaces flat and out of twist. Even with the partitions shown in Fig. 45, the stream was less solid than desirable and less solid than I believe it possible to attain. It did not seem to lie within the power of these partitions to remove all the twisting and disturbed condition of flow induced by the Siamese and the elbow.

It happened that at about the time of my experiments a convention of the New England Firemen's Association was held at Haverhill, Mass., and an exhibition was made of 2-inch Siamese streams from pipes of three different kinds, made by different parties. I noticed that with each of these streams there was proportionally very much more spraying than from a $1\frac{3}{8}$ inch nozzle from a single line of hose, and am inclined to attribute it to the disturbed condition in which the water reaches the nozzle.

As soon as there is opportunity I hope to construct another Siamese in which the three portions of water from the three lines of hose shall be kept separated by thin partitions until after passing the elbow and until reaching the play-pipe proper. The water passages will, moreover, be so designed as to avoid sudden changes of section, and care will be taken that axis of each of the three streams shall make the bend by a curve lying in a plane. With such a pipe it is expected to avoid twist of current and get a more solid stream.

Advantage of Siamese Nozzles and Large Streams.

We may add a word here as to the reason for the especial merit of these large streams. They are, of course, available only in cases where the water supply is especially ample. At many large factories the fire pumps are of capacity sufficient to supply one of these in addition to a convenient number of single streams, and on fire boats they can ordinarily be provided for. If supplied by city steamers it will ordinarily require the united efforts of three steam fire-engines of the usual size to supply one 2-inch stream; yet in a serious conflagration it may often be

the case that one 2-inch stream will do far more execution in stopping the progress of the fire than would the three single streams. It is a fact well known to firemen, and one which the writer has had good opportunity to observe personally, that a small stream is often almost wholly evaporated in the flames of a very hot fire; whereas with these larger streams, even though the same quantity be evaporated as before, enough water may be left to pass through the flames and burning gases to reach and chill the coals themselves.

EXPERIMENTS ON COMPARATIVE EFFICIENCY OF DIFFERENT KINDS OF NOZZLES.—(See drawings of nozzles on pages 318 to 325.)

The most of these experiments were made with the apparatus arranged as shown in Fig. 54, and in a number of the more important cases further experiments on the same nozzles were made with apparatus arranged as shown in Fig. 55. In a number of cases, after making the experiments with nozzles in one position, their positions were reversed, to make sure that the jet next wall was not shielded from air currents or affected differently from the outer one in any way. In no case was proximity of wall found to affect jet. Care was also taken in each experiment to sight the two streams out of wind with each other for the first part of their course, and thus insure their having precisely the same angle of elevation.

Comparison No. 8.—1⅛-inch conical nozzle *B* (Fig. 16), compared with 1⅛-inch conical nozzle *A* (Fig. 13). Both these nozzles were tested on the same kind of play-pipe, and the nozzles themselves were exactly alike, so far as any measurement or appearance could indicate, excepting only that in nozzle *B* the slight corner at end of cone was carefully rounded off. Experiment was made at 50 pounds pressure at base of play-pipes, and with nozzles at 60 degrees elevation. There was no wind, and conditions were favorable for accurate observations. By four successive trials another observer and myself arrived independently at the conclusion that *B* threw its stream just a little closer—that is, with a little less spraying than *A*—but that difference was very small. We also concluded that main body of stream and also the extreme jet averaged reaching a height of about 6 inches greater than *A* for pressure of 50 pounds, or was superior by about three-fourths of 1 per cent. It took very close watching to see any difference between these two nozzles.

Comparison No. 9.—1⅛-inch nozzle *P* (Fig. 23) (screw nozzle, so-called), compared with nozzle *A* (Fig. 13). Nozzle *P* differed from *A* in that diameter at end of play-pipe was 1¼ inches instead of 1½ inches. The comparison was made at 50 pounds pressure, 60 degrees elevation, with still air and conditions favorable for accurate observation. Trying the two nozzles simultaneously side by side, as in Fig. 54, unquestionably the jet from the screw

nozzle was at its summit 4 feet below summit of jet from nozzle *A*, and extreme point at which jet from screw nozzle could be called a good fire stream was 5 to 7 feet less than the corresponding point on jet from nozzle *B*. The screw nozzle thus appeared on the whole to be from 5 to 8 per cent. inferior to *A* in projecting power. This difference was undoubtedly due to the smaller water-way at end of play-pipe. Nozzle *P* is sold about 15 per cent. cheaper than *A*, but having been proved to be less effective, its manufacture is to be discouraged.

This and the next experiment illustrated the necessity of having throat of play-pipe of ample size, and indicated that the old-fashioned sporting play-pipe, so-called, which was about 5 feet long and converged throughout its length on a uniform taper, was not adapted to give such good results as are to be attained by a play-pipe in which stream is continued of approximately full size up nearly to the point of delivery, and it was by reason of these experiments that diameter of throat or end of standard play-pipe shown in Fig. 7 was made 1¾ inches in diameter.

Comparison No. 10.—1¼-inch nozzle *J* (Fig. 23) (screw nozzle, so-called), compared with 1¼-inch nozzle *e* (Fig. 11). These experiments were also made with two pipes tried simultaneously side by side, arranged as shown in Fig. 54, pressure at base of play-pipe 50.0 pounds, angle of elevation of jet 60 degrees. From position on Washington roof I concluded that unquestionably nozzle *J* was inferior to nozzle *e*, and that its jet was not projected so high as for nozzle *P* by about 6 per cent. on the average. The extreme drops from nozzle attached to the larger play-pipe went 3 or 4 feet higher than for nozzle *J*, and the limit as a fire stream appeared to be 6 or 7 feet higher. Examining both jets from below, unquestionably the stream from nozzle attached to the larger play-pipe sprayed the least; thus, for 20 feet distance from nozzle nearly all of the water from nozzle *e* goes through a circle 2½ inches in diameter, while for nozzle *J* it scattered over a circle of about 3½ inches in diameter. Examining both jets from Pacific roof, the nozzle on the larger play-pipe was seen to give decidedly the closer stream. Repeating experiment with 40 pounds pressure, the maximum height of jet from nozzle *J* was, on an average, about 4 per cent. less than from nozzle *e*.

Comparison No. 11.—1⅛ inch truncated cone nozzle *C* (Fig. 17), compared with nozzle *A*. This nozzle *C* was constructed as a result of experiments on distribution of velocity (see Fig. 61). Reasoning by analogy from curves of distribution for conical nozzle *B* and curve for pipe of uniform diameter, it was evident that within certain limits the addition of a straight cylinder to end of cone increased the retardation of the filaments of water next the side. It was thought, therefore, that possibly there would be less retardation of the outer portion of jet if the straight part were almost wholly removed from the ordinary nozzle. Then, too, it was desirable to learn whether this straight part was of any real advantage, even if of no disadvantage. Nozzle *C* was compared with nozzle *B*, in manner shown in Fig. 54, with pressures of about

50, 75 and 105 pounds at base of play-pipe, and angle of elevation of 75 degrees. These two nozzles were also compared under the conditions shown in Fig. 55, with pressure of 50 pounds at base of play-pipe. From all these comparisons it was concluded that the difference between the jets was practically inappreciable, and though perhaps the height of jet from *C* was 1 per cent. less, certainly the difference in distance reached by main body of the two streams could not have averaged greater than 2 per cent. without being plainly noticed. I am inclined to think that if corner at end of taper had been smoothly rounded off as in *B*, Fig. 16, or as in the standard nozzle, Fig. 7, the comparison would have been slightly more favorable to *C*.

Comparison No. 12.—Nozzle *D* (Fig. 15) compared with nozzle *A*. These two nozzles were compared playing simultaneously, in the manner shown in Fig. 55, under a pressure of 50 pounds. It was not possible to detect any difference in the character of the two jets. This experiment was not made under such favorable conditions as some of the others, and a difference of 2 per cent. in distance reached may have escaped detection. The comparison is of interest, as showing that the enlargement of diameter of nozzle next end of play-pipe, customary with most makers, causes little if any interference with flow.

Comparison No. 13.—Uniform acceleration nozzle *E* compared with nozzle *B*.

In preparing apparatus for these experiments, the writer was led to design two nozzles of this form, from having noticed in several cases the smooth, transparent, undisturbed appearance of a stream falling vertically from the contracted end of a pipe, and falling by direct influence of gravity on the particles forming the jet, rather than by the propulsion from a high pressure within the pipe. A very little study showed the form to be that due to uniform acceleration of velocity, and though the analogy was of course not strong enough to amount to a real reason why the form of this smooth and undisturbed jet should serve as a good form for a nozzle, yet the experiment was thought worth trying, and two nozzles were constructed with great care. One of these is shown in Fig. 14 and the other in Fig. 18. They were bored and polished to fit templets which were laid out with micrometer calipers and cut with great care. The templets probably nowhere varied more than, say, two or three thousandths of an inch from the mathematical curve, and the nozzle as finally finished apparently nowhere diverged more than $\frac{5}{1000}$ inch from the mathematical curve, and both were smoothly polished, and in the one shown in Fig. 14 the joints were so finely fitted that they could hardly be seen from the inside. The elements for the curves were, for Fig. 14, diameter at beginning, $2\frac{1}{2}$ inches; diameter at end, 1.133 inches.

Distance of beginning from plane of zero velocity, 2.99 inches. Length along axis 7 inches, followed by 1 inch in length of uniform diameter, with the slight corner between the curve and the straight part rounded off.

For Fig. 18, diameter at beginning, 1.70 inches; diameter at end, 1.122 inches; distance of up-stream end from plane of zero velocity, 0.712 inches; length of curve along axis, 3.00 inches; followed by 1 inch in length of uniform diameter; these tapering and cylindrical surfaces merging into each other almost imperceptibly.

Subsequent to the making of the nozzles my attention was called to a paper by Mr. A. F. Nagle, in Transactions Am. Soc. M. E. for 1888, page 505, on the Best Form of Nozzles, etc., in which Mr. Nagle expressed the opinion that this form of nozzle must be the best. I therefore experimented with it with much interest.

A comparison of nozzle *E*, Fig. 14, with nozzle *B* on the pipe shown in Fig. 13, was made in the manner shown in Fig. 55 with 50 pounds pressure on two different occasions, one time being at the exhibition made in the presence of the corps of inspectors. The closest inspection failed to show any material difference in the solidity of the streams or in the distance reached. If anything, the jet from the uniform acceleration nozzle sprayed the most within the first 40 feet of the course and was a little the less solid at the further end. These conditions were favorable for a very accurate comparison. Examining the two jets near orifice, there was no appreciable difference noticed in smoothness at surface of jet.

A comparison was also made at the site shown in Fig. 54 at very high pressure, trying one nozzle at a time, first *B* and then *E*. In this comparison the general result was that at about 105 pounds static pressure at base of play-pipes the height of jet as a good fire stream was fully 5 per cent. less for the uniform acceleration nozzle than for the conical nozzle *B*, but the height to which the extreme drops were thrown appeared much the same with each.

Comparisons Nos. 13 and 14 conclusively show that this "uniform acceleration" curve possesses no special merit as a form for a nozzle.

On looking over Mr. Nagle's paper, it does not appear that his argument in favor of this form for nozzles is a logical one at all, any more than the mere notion mentioned on page 88, which led me to have two nozzles of the form made.

In Professor Merriman's recent valuable treatise on hydraulics, too, the mathematical derivation of the curve for a uniform acceleration nozzle is presented as though there were good reason to expect this form of nozzle to be the best; but in both these demonstrations must not the starting point, that this uniform acceleration of velocity will give the best results, be classed as resting on a notional rather than a rational basis? It may be mentioned that in any case the derivations of the curve, as given, are merely convenient approximations and are not mathematically exact, for velocities of all particles in each plane of section are assumed to be uniform, which we well know not to be the case; and even if they were uniform at end, the successive surfaces in which all the particles issuing in a given plane would be found as they approached orifice would not be planes, but surfaces of revolution subtending equal distances on the various paths of the fluid fillets from center to circumference. Why should uniform acceleration, which involves supposing the force in its full magnitude applied instantly, continued uniform for a brief interval then all instantly removed, be expected to give better results than a force gradually applied and gradually increased in magnitude, as is the case in a plain conical nozzle? Is not the argument as good in one case as in the other, and of no certain value in either? And is not Mr. Nagle's argument as to proper form for diverging tubes, in the paper above referred to, equally without substantial basis? Since extreme divergence near end would probably lead to formation of eddies.

I fancy that for the best efficiency of nozzles as for turbines it is not a question of having the curves follow any given equation, but almost wholly a question of making curves of such form that eddies or tendencies toward eddies or unsymmetrical distribution of velocity may be avoided.

One other criticism may be made on Mr. Nagle's nozzle (shown in Fig. 128, page 506, Transactions Am. Soc. Mech. Eng., 1888), viz.: After increasing the velocity to almost its extreme limit, the water is carried within the walls of nozzle for a comparatively long distance, thus tending to incur more loss by friction against walls and consequent greater retardation at side of jet than if the velocity were kept low up nearly to end of nozzle.

It has been thought well to discuss this form of nozzle at greater length by reason of the prominence given it by the publications of Mr. Nagle and Professor Merriman, already referred to.

Comparison No. 14.—Comparison of small uniform acceleration nozzle *F* (Fig. 18), on conical pipe shown in Fig. 13, with nozzle *B* (Fig. 16) placed on a similar pipe. These were compared in manner shown in Fig. 54 at 60 degrees elevation with 50 pounds pressure. Careful examination failed to show any appreciable difference in the character of the jets from these two nozzles; certainly the difference in height to which jets were projected was not over one per cent.

Comparison No. 15.—The bottle-shaped nozzle *L* (Fig. 20) compared with conical nozzle *B*. Both were attached to play-pipes of the kind shown in Fig. 13, and were tested side by side in the manner shown in Fig. 55, at a pressure of fifty pounds. Hardly any difference could be detected in distance reached by the two jets, though, on the whole, that from *L* appeared to be slightly inferior. The difference, if any, was probably not greater than two per cent. This comparison was rather quickly made, however, and although no reason appears for doubting its accuracy, it should be understood that the comparison was less complete in its range than most of the others.

Comparison of Choke-Bore Nozzles.

These nozzles termed "choke-bore" nozzles were constructed with a slight contraction of water-way close to the orifice, with the idea that possibly this slight contraction of water-way might force those particles of water next to the outside of jet a little ahead of their normal position, and thus tend to prevent the retardation at side of jet (shown in Figs. 61 and 62). The reason for thinking that possibly this might be the case was that the writer, in measuring, a number of years since, the distribution of velocities in an open river channel in the vicinity of a bridge pier, found the obstruction by the pier to force the curve of velocities slightly ahead at points a few feet from the pier.

In making flume measurements, too, of the quantity of water passing a mill-race, by the Francis method, with floating tubes, the writer had, in the course of gaugings at certain race-ways where there was a contraction of width of flume immediately above the site of the gauging, found a velocity at a short distance from side even greater than that in the center. Various other somewhat similar phenomena noted in the writer's experience indicated as probable that when an obstruction is placed in a water-course where there is a certain rate of flow, the inertia of the water moving immediately adjacent to this obstruction tends to produce the increase of velocity necessary to make up for lost area of section, mainly in the immediate vicinity of the obstruction; rather than to let this necessary increase of velocity be uniformly distributed throughout the cross-section.

It looked reasonable to suppose that some such action as this might obtain in nozzles, and prior to the experiments it was thought by the writer that perhaps this might prove a sufficient cause for the superiority of a ring nozzle having some certain projection of shoulder over the smooth form.

Various nozzles as mentioned next in order were therefore constructed one after another, in the effort to increase the proportional velocity at side of jet. We may say at once that our hopes were disappointed and none of these choke-bores proved to have any merit over the smooth cone.

Comparison No. 16.—The long choke-bore, nozzle *Q*, Fig. 21, was therefore constructed, and was compared with the conical nozzle *B*, under the conditions shown in Fig. 54, with 50 pounds pressure at base of play-pipe, and an angle of 60 degrees elevation. It appeared that nozzle *Q* was in nowise superior to nozzle *B*, and that in general the extreme height of its jet was not so great by about 1 foot. Judging of the two as good fire streams at 40 pounds pressure, the highest point at which they could be classed as such was 3 or 4 feet less with *Q* than with *B*. On the whole, I conclude nozzle *Q* was from 2 to 4 per cent. inferior to nozzle *B* in projecting power.

Comparison No. 17.—The short 1⅛-inch choke-bore nozzle *H*, Fig. 19, compared with conical nozzle *B*. Nozzle *H* was constructed at the same time and with the same object in view as for the experiment last described. Experiment was made with 50 pounds pressure and also with 40 pounds pressure at base of play-pipes, and with apparatus arranged as shown in Fig. 54. I concluded nozzle *H* to be in nowise superior to nozzle *B*, and that the summit of its jet did not average so high by about 3 feet.

Nozzle *H* was then tested side by side with nozzle *J*, and the streams from the two appeared almost identical. Thus, on the whole, it was concluded that jet from nozzle *H* reached a distance 3 per cent. less than that from *B*.

Comparison No. 18.—Short 1⅛-inch choke-bore nozzle *q* compared with conical nozzle *B*. Test made under conditions shown in Fig. 54, 60 degrees elevation, 50 pounds pressure, but with only one stream playing at a time. From trying first one, then the other, and then repeating, my assistant and myself independently reached the conclusion that *q* was probably slightly inferior to *B* in projecting power. It was difficult to perceive any difference, and it appeared certain that difference was not more than 1 per cent. Apparently the stream from *q* wavered more and broke into drops a little sooner near the top.

Comparison No. 19.—1¼-inch taper ring *p* (Fig. 35) compared with 1⅛-inch smooth nozzle *B*. The taper-ring nozzle gave a jet which at time of measurement of co-efficient of discharge was seen to be so plainly inferior by reason of greater spraying and apparently disturbed condition of current that the more complete comparison as per Fig. 54 was not made.

Comparison No. 20.—Nozzle *K* (Fig. 22) compared with nozzle *B*. These two nozzles were compared playing simultaneously, under the conditions shown in Fig. 55, at 50 pounds pressure at base of pipe. An increased amount of spraying due to the obstruction in water-way was very evident, and distance reached by jet was very appreciably less than from nozzle *B*, say 10 per cent. The difference in distance reached by jet was not determined with great exactness by reason of a slight wind which existed at the time.

Comparison No. 21.—Comparing the Silsby long cone with the Silsby short cone (Fig. 24), by trying first one and then the other and then repeating, at an elevation of 60 degrees with 50 pounds pressure, it appeared that there was no material difference in the maximum elevation attained by the two jets, but on the whole it seemed as though the long nozzle gave a slightly more solid stream.

Comparison No. 22.—Nozzle *A*, on flexible play-pipe of uniform diameter shown in Fig. 26, compared with stream played simultaneously from nozzle *B*, attached to the ordinary tapering play-pipe shown in Fig. 13. Experiments

were made with apparatus arranged as in Fig. 54, with pressure at 50 pounds and an elevation of 75 degrees. The conditions for observation were excellent in every way, and I examined jets from both the Pacific and the Washington roof. Jet from the nozzle on flexible pipe, shown in Fig. 26, was on an average fully 1 foot to 1½ feet inferior in height reached, to jet from nozzle *B*. (Experiment No. 1 would indicate that probably half of this difference was due to difference in the nozzles, leaving the other half to be accounted for by difference in the forms of play-pipes.) On the closest examination I could detect no difference in the spraying quality of the two jets. Drops of water at summit of both streams were about ⅜ inch in diameter. This is of special interest as showing that the special form of play-pipe has little influence on character of jet so long as diameter at end of play-pipe and beginning of nozzle proper is reasonably large. And it is of interest also as showing that this flexible play-pipe, which is quite popular among firemen, is, when kept straight, but very little inferior to the best in projecting power.

Comparison No. 23.—Play-pipe shown in Fig. 25 with rough interior surface and 1-inch outlet, compared with nozzle of same size (*c*) on play pipe with smooth interior shown in Fig. 13. The comparison was made as shown in Fig. 54 at 75 degrees elevation and with 50 pounds pressure, and all conditions were very favorable for accurate observation.

The play-pipe shown in Fig. 25 was of a kind often found in the market. It was made from a brass casting, and its outside was nicely polished, while its inside was left rough as it came from the foundry sand. It was found that the jet from this reached a height 12 feet less (about 13 per cent.) than jet from the smooth play-pipe.

There was one very remarkable fact, however, noticed, which is worthy of mention. The drops from this rough pipe were at the summit of double the size of those from the higher jet. They averaged about ½ inch in diameter. This was unquestionably evident, as from the station on the Pacific roof I stood close to summit of jet.

In this connection it may be remarked that in comparing the jet from small Siamese, which by reason of its too-small play-pipe reached a less height than jet from the larger barrel, the drops composing the summit of the inferior jet were much larger and closer together than those from the jet attaining the greater height, being, in fact, irregular lumps of water rather than drops.

Ring Nozzles *vs.* Smooth Nozzles.

Considerable interest attaches to the comparison between ring nozzles and smooth nozzles, for although at the present time the best authorities agree in the opinion that a smooth nozzle will throw equally as

good a stream as a ring nozzle, yet there are many experienced firemen who consider that the ring nozzle throws a cleaner and more solid stream, and who maintain their opinions very positively. It was intended, if possible, to settle this question by the following experiments, and the result of the following comparison shows that the ring nozzle possesses no advantage whatever over the smooth; but the difference in the character of the streams from the two nozzles was almost inappreciable, both as to distance attained by the extreme drops and also by the main body of the jet. As a result of all the comparisons it was concluded that the extreme height attained by jet from smooth nozzle was about 1 per cent. greater than height of jet from ring nozzle discharging the same quantity of water under the same pressure. The spraying from the ring nozzle was certainly slightly greater than for the stream from the smooth nozzle. On the whole, it was concluded that the distance to which the stream could be classed as a "good fire stream" was 3 per cent. less with the ring nozzle than with the smooth nozzle, and since the ring nozzle discharges only about three-fourths as much water as does the smooth nozzle with the same size of orifice, there is, in addition to difference noted above, a still further superiority in distance reached by a stream from a smooth nozzle over a stream from a ring nozzle of the same diameter. Although the difference in the reach and solidity of jets from ring nozzles or from smooth nozzles is so small as to be almost of no practical importance, yet the use of the ring nozzle is to be discouraged, since it makes a show of playing a larger stream than is the fact. Details regarding the comparisons are given below:

Comparison No. 24.—1¼-inch square ring nozzle (*l*) of the ordinary form, compared with 1⅛-inch smooth nozzle *B* under conditions shown in Fig. 54, at 50 pounds pressure and 60 degrees elevation of jet. The height of jet from ring nozzle was from 1 to 2½ per cent. less than from smooth nozzle, and unquestionably there was more spraying from the ring nozzle jet.

Comparison was then made with both jets vertical, first with 50 pounds pressure and afterwards with 40 pounds pressure at base of play-pipe. As the mean of these two experiments, ultimate height appeared the same within less than 1 per cent., but water at top of jet was certainly in less solid and compact form in jet from ring nozzle than from smooth nozzle.

Comparison No. 25.—In order to make the comparison still more conclusive, a ring nozzle was construced (see nozzle *k*, Fig. 33) of such diameter as to discharge almost exactly the same quantity of water as did the 1⅛-inch smooth nozzle *B;* but as finally made the diameter proved a few thousandths of an inch larger than intended, and thus the discharge was nearly 2 per cent. greater than the discharge from *B*. This difference was of course too small to affec

the following comparison. This nozzle *k* was constructed with especial care to have the face of the ring as nearly in a plane surface as possible, and the edge was finished as sharply as brass could be worked and was not dulled by polishing with emery cloth. The several comparisons made between jet from this nozzle *k* and from nozzle *B* are considered very satisfactory.

The comparison was made first under the conditions shown in Fig. 55, the two jets playing simultaneously in each case, and the pressures being adjusted so as to be equal within $\frac{1}{10}$ pound or less. The conditions were such that a difference of less than 1 per cent. in distance reached could be easily detected. The two jets agreed with surprising closeness. It was almost impossible to detect any difference in their path until very near the end; but it was evident that the extreme drops from the ring nozzle attained in general a distance about 1 per cent. less than those from the smooth nozzle, and as a "good fire stream" it was judged that the jet from smooth nozzle attained a distance from 2 to 4 per cent. greater. Unquestionably there was a little more spraying on the ring nozzle jet than on the smooth. This experiment was afterward repeated, both as shown in Figs. 54 and 55, in the presence of the corps of inspectors, and after making one experiment the nozzles were reversed in position, each being placed on the other's play-pipe, all else remaining the same. The general result was again found as already stated.

Ring nozzle *k* was afterward compared with smooth nozzle *B* at the unusually high pressure of about 103 pounds at base of play-pipe and 75 degrees elevation, the comparison being made at site of Fig. 54, but with only one stream playing at a time. So far as could be seen the extreme drops of the two jets reached the same height, and main body of jet at summit was about 2 per cent. less for the ring nozzle, and the height at which the two were classed as "fair fire streams" was considered to be 5 per cent. less for the ring nozzle.

Comparison No. 26.—Ordinary undercut ring nozzle *n* (see Fig. 30) compared with smooth conical nozzle *B*. This undercut nozzle, so-called, is of a style which is considered by many good firemen to give a superior stream; but the reason usually given for this opinion is rather more amusing than scientific, namely, that it holds back the slow, disturbed currents of water near side of play-pipe and gives out only the central swift and least disturbed portion for the jet. Comparisons between these two nozzles, made at 60 degrees elevation, as in Fig. 54, and also at a lower elevation as in Fig. 55, failed to show any appreciable difference in jet from this form of nozzle and the more common square ring nozzle last described.

Comparison No. 27.—Narrow ring nozzle *l*, Fig. 29, was constructed subsequent to a portion of the above experiments, partly from the same motives that led to the construction of the choke-bore nozzles already mentioned. It will be noted that its discharge was almost identical in quantity with that from smooth conical nozzle *B*, and several comparisons were made therefore between these two playing side by side. The general result of these comparisons was to indicate that this narrow ring gave a stream slightly superior to that from the wider rings, and it could not be said that it was any inferior to the jet from the smooth nozzle. It appeared certain, however, that it was not superior. In this comparison the pressure, though generally 50 pounds, was carried up to 100 pounds in one experiment made at an angle of 75 degrees.

Comparison No. 28.—Undercut cap *o*, Fig. 32. By reason of failure to find suitable opportunity when there was no disturbance from wind, this comparison was not carried out with such detail as the most of those already described. It was found by the preliminary experiments at 50 pounds pressure that the jet from this nozzle was certainly very much poorer than from the smooth conical nozzle, and apparently poorer than from any other form of nozzle tried. The form of jet appeared slightly unstable, as though due to an internal disturbed condition. There were also a few lines or nodes occasionally apparent on exterior of jet at a distance of a foot or so from nozzle, but they were not sharply defined and their position was unstable.

Comparison No. 29.—Siamese nozzle with 3-inch straight barrel compared with Siamese nozzle with play-pipe or barrel 4 inches in diameter at base (see Fig. 44). Comparison made at 75 degrees elevation at site shown in Fig. 54, trying first one and then the other. In both these comparisons it was found that the height of extreme drops and of the main body of stream at its summit was from 6 to 8 per cent. less than for the Siamese with the smaller play pipe. It appeared that the jet from the larger play-pipe could be classed as a "good fire stream" for a height from 8 to 12 per cent. greater than the jet from the smaller, but the remarkable fact was noted that the size of drops and general solidity of jet was better with this smaller play-pipe.

Comparison No. 30.—Several comparisons were made between the smooth 2-inch Siamese nozzle, and also the 1¾-inch nozzle and the ring nozzle shown in Figs. 39 and 41. So far as could be detected these ring nozzles gave jets equally as close as those obtained from the smooth nozzle, but, as mentioned previously, I do not consider that any of these Siamese jets were so solid and free from spraying as it is possible to obtain.

In closing this subject, the writer would suggest two rather fine points upon which further experiment would be of practical value; the first is, to determine by careful experiment the conditions as to form or smoothness of play-pipe necessary to insure that the drops into which the jet or stream breaks toward the end be of the largest possible size; for such coarse drops will be less likely to evaporate in passing through the flames.

It so happened that in two cases (comparisons Nos. 23 and 29), where the nozzle as a whole was inferior in projecting power, the drops at end of the lower jet were certainly of double the size of those belonging to the other stream playing at its side.

It is surmised that this may have been due to the action of the greater friction loss within the play-pipe, etc., in removing or absorbing the influence of irregular currents originating within the hose.

The second point suggested for further experiment is, that when it is

found expedient to make further tests on jets, it would be well to get some quantitative measurement of the proportion of the whole volume leaving the nozzle, which attains some given position near end of jet.

Thus, for instance, with a jet under 50 pounds pressure, arrange a tank or weir to measure the water received into a vertical opening say 2 feet square, placed, say, 80 or 100 feet distant from nozzle and at an elevation of 30 feet above it.

This would settle conclusively whether there was a very considerable difference in the thinness to which jets whose extreme drops reached the same distance tapered out toward the end, as stated by Captain Eyre M. Shaw in his book on fire protection, and thought to be dependent on the form of nozzle, but of which the writer found no evidence.

The writer did not find any very marked difference between different nozzles in this respect, although it was looked for; and although such eye estimates are, of course, less positive than actual measurements, it is to be said in this connection that by reason of having such a near point of view for examining the jets under comparison, and also by reason of their being seen against the excellent background furnished by the adjacent brick wall, and also especially from the fact that in most cases the comparisons were made with the two jets playing side by side, it is not thought that the comparisons can have been very much in error.

Distribution of Velocity in Jets.

This is a matter upon which the writer was unable to find that previous experiments had been made. The following investigation was undertaken, therefore, in the hope that it might lead to improvement in form of nozzle.

The apparatus is shown in Fig. 60 and the results in Figs. 61 and 62.

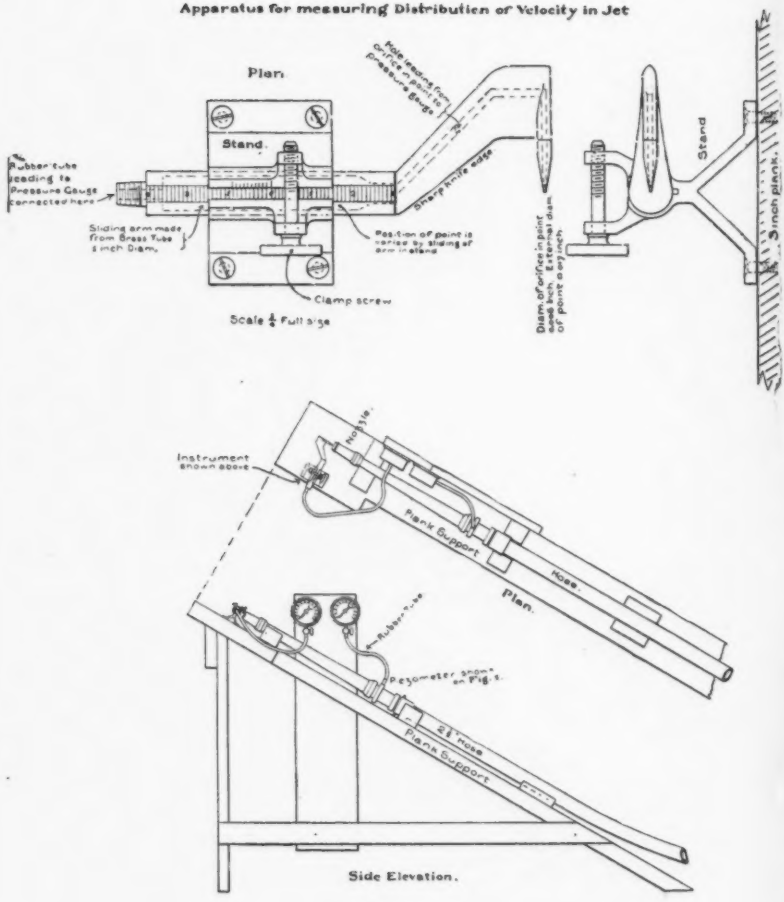
The instrument shown in Fig. 60 was designed by the writer specially for these experiments and proved all that could be desired. The stiff form and secure clamp prevented all vibration, and the sharp knife-edge of bar opposed so little resistance to current that it was found to cause no disturbance whatever in the relative distribution of velocities. In other words, the curves of distribution were in almost every case symmetrical on the two sides of center (see Fig. 62), although the velocities at side of jet furthest from stand were measured with the bar of instrument passing almost entirely through jet and cutting it in halves. The main instrument was of brass, but the small point was composed of an alloy of gold tipped with iridium, and was in fact the tip from a stylographic pen having an orifice of unusually small size.

This point was carefully re-finished by a watchmaker in order to get its minute end faced up true and square. The diameter of orifice was about six-thousandths of an inch and external diameter of the point at its end 0.017 inch. By means of the vernier and scale engraved on the stand and body of instrument it was possible to determine position of point within a few thousandths of an inch. The greatest care was taken that even the most minute leakage from the gauge connections should not exist, as it was realized that by reason of the small size of orifice such leakage would have proved fatal to accuracy.

The two gauges used were new and excellent standard test gauges of the Bourdon style, graduated to single pounds, but read by estimation to tenths of pounds. At the close of the experiments these gauges were both compared with one of the mercury columns and proper corrections determined. These gauges were selected rather than the mercury columns by reason of their greater portability ; but the writer now regrets that he did not make use of the mercury gauges, for since the rest of the apparatus proved accurate and the measurements definite to an unexpected degree, it would have been of some interest to have had means for measuring the pressures with certainty to within a few hundredths of a pound.

Fig. 60.

Apparatus for measuring Distribution of Velocity in Jet



Complete Apparatus.
Scale ⅛ of full size.

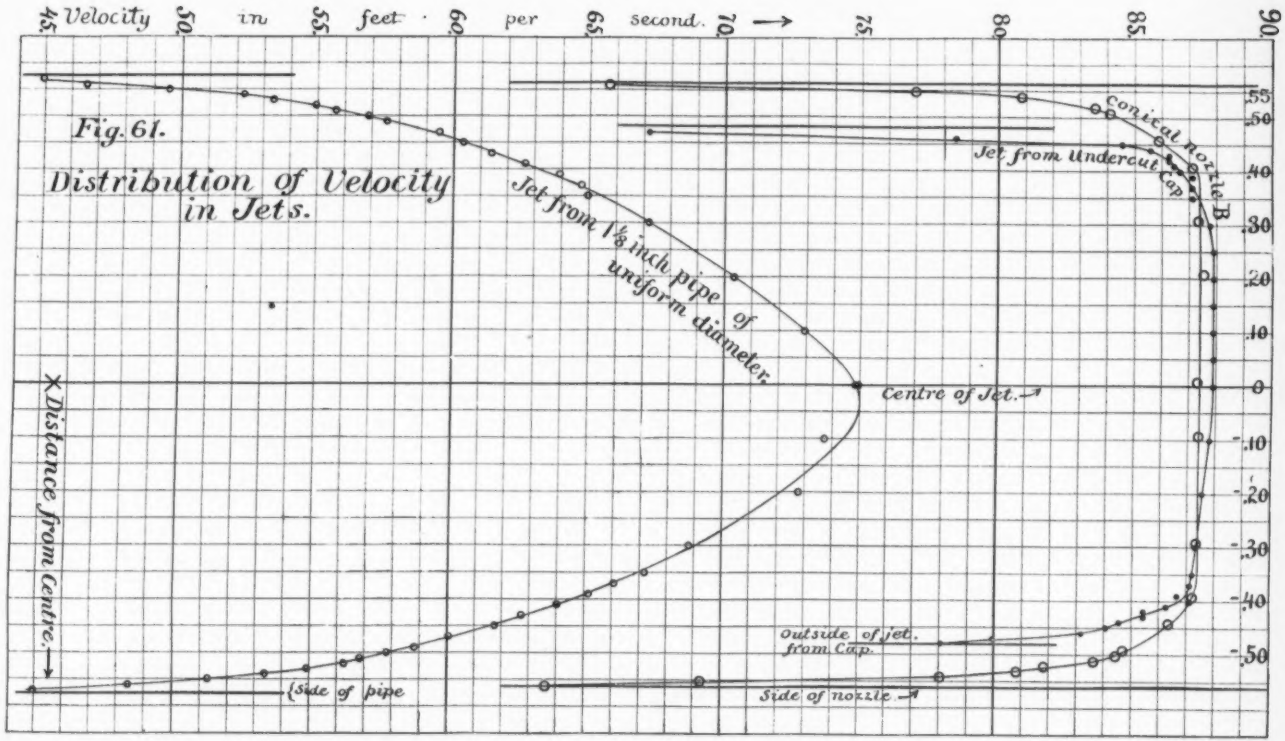


Fig. 61.

Distribution of Velocity in Jets.

These Bourdon gauges, however, worked unusually well, and there is no reason to think their indication more than, say, two-tenths of a pound in error.

Water was supplied from the city reservoir through the hydrants and the 2½-inch hose, and the pressure was regulated by the hydrant gate.

There were jets from about a dozen different nozzles experimented upon in this manner.

A single sheet of the reduced notes is reproduced here to illustrate the method followed (see Table No. 13).

As it will be remarked that the time occupied by each observation was rather short, we may remark that care was taken to give the gauge ample time to establish its equilibrium and come to rest after each change in position. Under these very high velocities it took but a very short time for the gauge to settle. This particular sheet happens to be one taken after considerable facility in the quick manipulation of the instrument had been acquired.

In all the plottings the co-efficient of the instrument has been assumed to be unity and the velocity is thus taken as that corresponding to the pressure shown by the gauge attached to the instrument. The velocity was generally measured at from $\frac{1}{8}$ to $\frac{1}{2}$ inch away from the orifice, and in case of the contracted streams the velocity instrument was set with its point in the plane of greatest contraction.

The diameters of the jets were calipered with much care, but it was found difficult to determine these diameters nearer than $\frac{1}{100}$ inch, by reason of the incipient spraying already referred to.

Fig. 61 gives three representative curves plotted on a magnified scale. The plotting is made with actual distances from center as ordinates and actual velocities in feet per second as abscissæ.

A point which at once strikes one as of special interest is the difference between the jet from a conical nozzle or an orifice with sharp contraction, and a jet from a straight pipe of uniform width. The velocity in the jet from the nozzle or sharp-edged orifice is seen to be almost absolutely uniform for about four-fifths of the whole distance from center outward to circumference, while the jet from the pipe of uniform diameter is retarded all the way from the center outward.

This pipe of uniform diameter it should be said was a good, straight, average, smooth piece of brass tubing 5 feet long and $1\frac{1}{8}$ inches internal diameter. It was not "seamless drawn" as would have been preferable,

but was "brazed tube," and there was thus a slight difference in character of service along this seam, which is perhaps the cause of the curve shown in Fig. 61 not being quite symmetrical. This 5-foot piece of $1\frac{1}{8}$ tubing was connected to the end of one of the $1\frac{1}{8}$-inch conical nozzles by appropriate screw threads and couplings, and this nozzle was in turn attached to play-pipe in the same way as shown in the lower sketch of Fig. 60, except that of course it carried the play-pipe, etc., farther up stream along its plank support.

The character of the jet from the straight pipe was very much inferior to that from a conical nozzle; it sprayed and spread out much more quickly.

It thus appears that excessive retardation of velocity in outer layers tends to increase the spraying and to decrease the distance to which the jet will retain its solidity. This might naturally be expected.

These experiments on distribution of velocity are also of great interest in illustrating the reason for the value of the co-efficient of discharge for a tapering nozzle. They indicate that the reduction of its value below unity is due only to the retardation of velocity of the outermost fluid fillets caused by friction against walls of orifice.

That the velocity within the central portion of the jet is very nearly, if not quite, that theoretically due to the pressure, is indicated by the following comparison:

Nozzle experimented upon.	Pressure Indicated by Gauge at base of Play-pipe, corrected for gauge error and reduced to mean value.	Static Pressure corresponding corrected for Velocity past Piezometer.	Theoretical Velocity due Static Pressure at base of Play-pipe.	Velocity indicated by Instrument in central portion of jet (corrected).	Difference.
	Lbs. sq. in.	Lbs. sq. in.	Ft. p. sec.	Ft. p. sec	Ft. per sec.
A (conical)	50.0	52.0	87.89	87.45	+0.44
B (conical)	50.0	52.0	87.89	87.33	+0.56
c (truncated cone)	50.0	52.0	87.89	88.54	−0.65
E (unif. accel.)	50.0	52.1	87.97	87.20	+0.77
i ($1\frac{1}{4}$ sq. ring)	50.0	51.8	87.71	87.45	+0.26
n ($1\frac{1}{4}$ u. c. ring)	50.0	51.6	87.54	87.12	+0.42
k (1.314 sq. ring)	50.0	52.1	87.97	87.73	+0.24
l ($1\frac{3}{16}$ sq. ring)	50.0	52.0	87.89	87.40	+0.49
o ($1\frac{1}{4}$ cap)	50.0	51.1	87.12	87.86	−0.74
Average difference					+0.20 ft. per second.

Average proportional difference between theoretical velocity and actual velocity in central portion of jet = 0.00227.

We should naturally expect that the friction within the play-pipe proper would absorb some force, and thus that the instrument velocity might be very slightly less than the theoretical velocity due to pressure measured at base of play-pipe.

This difference actually found is so very slight that the small gauge errors might account for it, therefore it is a matter of regret that the more accurate mercury gauges were not used.

We can, however, I think, safely say that velocity at central portion of jet equals the theoretical velocity due the head at base of play-pipe, providing play-pipe be short, of good diameter and smooth.

Upon Fig. 62 as many representative curves have been traced as was possible without so confusing the lines as to make the diagram of little or no value. The curves obtained with the other nozzles are all similar; even that with the smooth 2-inch nozzle for Siamese was similar near the side. We see revealed by these curves the interesting fact that about two-thirds of the whole distance from center to circumference the velocity remains the same as at center, and that at $\frac{1}{16}$ inch from the wall of this orifice the velocity was only 5 per cent. less than at center of jet.

The difference between the relative arrangement or distribution of velocities for the contracted nozzles or ring nozzles and the smooth nozzles is less than I had expected to find, especially so in the case of jet issuing from the re-entrant sharp tube (*o*).

It will be seen, however, that with *o* there was less retardation of the fluid fillets next outside of jet than with *B*, and the reason the form of jet was no better is probably that there was a disturbed condition or unstable motion within the jet as it issued, due to some unstable equilibrium in the currents approaching the orifice.

It is of interest to note that with the uniform acceleration nozzle *E*, Fig. 14, the influence of the length which current travels within nozzle after raised to a high velocity is plainly shown in the curve of distribution of velocities by a greater retardation near side.

On the other hand, the velocity close to outside of jet from the truncated cone nozzle is less retarded than the jet from any other form of nozzle tested, except the ring nozzles.

That the observations are probably accurate is indicated by the closeness with which the observations on the two sides of center agree.

It is of interest to compute the total retardation exhibited by one of

TABLE No. 13.

Distribution of Velocity in Jets. $1\frac{1}{8}$ Inch Uniform Acceleration Nozzle (*E*).

(Sample Sheet of Observations.)

Time—October 6th, 1886.	Scale Reading.	Distance from Center.		Gauge at Base of Play-pipe.					
		Actual.	Proportional.	Observed Reading. (Ashcroft Gauge).	Reading Corrected for Gauge Error.	Mean Value for Comparison.	Variation from Mean Value.	Correction to Mean Value for Velocity past Piezometer.	Static Pressure.
P.M.							Per Cent.		
3 37	— .00	+ .011	.019	50.0	49.5	50.0	1.0	2.1	52.1
3 38	— .10	— .089	.157	50.0	"	"	"	"	"
3 38	— .30	— .289	.510	50.0	"	"	"	"	"
3 39	— .35	— .339	.598	50.0	"	"	"	"	"
3 40	— .37	— .359	.633	50.0	"	"	"	"	"
3 42	— .39	— .379	.668	50.0	"	"	"	"	"
3 43	— .41	— .399	.704	50.0	"	"	"	"	"
3 43	— .43	— .419	.739	50.0	"	"	"	"	"
3 44	— .45	— .439	.774	50.0	"	"	"	"	"
3 45	— .47	— .459	.810	50.0	"	"	"	"	"
3 46	— .49	— .479	.845	50.0	"	"	"	"	"
3 47	— .50	— .489	.862	50.0	"	"	"	"	"
3 48	— .51	— .499	.880	50.0	"	"	"	"	"
3 49	— .52	— .509	.898	50.0	"	"	"	"	"
3 50	— .53	— .519	.915	50.0	"	"	"	"	"
3 51	— .54	— .529	.933	50.0	"	"	"	"	"
3 52	— .55	— .539	.951	50.0	"	"	"	"	"
3 53	— .56	— .549	.968	50.0	"	"	"	"	"
3 54	— .57	— .559	.986	50.0	"	"	"	"	"
3 54	— .58	— .569	1.004	50.0	"	"	"	"	"
3 55	— .59	— .579	1.021	50.0	"	"	"	"	"
3 57	+ .00	+ .011	.019	50.0	"	"	"	"	"
3 58	+ .10	+ .111	.196	50.0	"	"	"	"	"
3 59	+ .20	+ .211	.372	50.1	49.6	"	0.8	"	"
4 00	+ .30	+ .311	.549	50.0	49.5	"	1.0	"	"
4 01	+ .35	+ .361	.637	50.0	"	"	"	"	"
4 01	+ .37	+ .381	.672	50.0	"	"	"	"	"
4 02	+ .39	+ .401	.707	50.0	"	"	"	"	"
4 02	+ .41	+ .421	.743	50.0	"	"	"	"	"
4 03	+ .43	+ .441	.778	50.0	"	"	"	"	"
4 03	+ .45	+ .461	.813	50.0	"	"	"	"	"
4 04	+ .47	+ .481	.849	50.0	"	"	"	"	"
4 05	+ .49	+ .501	.884	50.0	"	"	"	"	"
4 06	+ .50	+ .511	.901	50.0	"	"	"	"	"
4 06	+ .51	+ .521	.919	50.0	"	"	"	"	"
4 07	+ .52	+ .531	.937	50.0	"	"	"	"	"
4 08	+ .53	+ .541	.954	50.0	"	"	"	"	"
4 08	+ .54	+ .551	.972	50.0	"	"	"	"	"
4 09	+ .55	+ .561	.990	50.0	"	"	"	"	"
4 10	+ .56	+ .571	1.007	50.0	"	"	"	"	"
4 11	+ .57	+ .581	1.025	50.0	"	"	"	"	"
4 12	+ .58	+ .591	1.043	50.0	"	"	"	"	"
4 14	+ .59	+ .601	1.060	50.0	"	"	"	"	"

Diameter of orifice, 1.133 inches. ∴ radius, 0.567 inch.

TABLE No. 13—(*Continued*).

Gauge at Base of Play-pipe.	Gauge Connected to Velocity Instrument.						
Velocity Corresponding to Static Pressure.	Observed Reading. (Crosby Gauge No. 2.)	Correction for Gauge Error.	Correction for Variation of Pressure from Mean.	Corrected Pressure on Instrument. Pounds.	Corrected Pressure on Instrument. Feet.	Corresponding Velocity.	Ratio to Velocity at Center, 87.28.
87.97	50.1	+ 0.6	+ 0.5	51.2	118.2	87.20	.9991
"	50.1	"	+ 0.5	51.2	118.2	87.20	.9991
"	50.0	"	+ 0.5	51.1	118.0	87.12	.9982
"	50.0	"	+ 0.5	51.1	118.0	87.12	.9982
"	50.0	"	+ 0.5	51.1	118.0	87.12	.9982
"	50.0	"	+ 0.5	51.1	118.0	87.12	.9982
"	50.0	"	+ 0.5	51.1	118.0	87.12	.9982
"	50.0	"	+ 0.5	51.1	118.0	87.12	.9982
"	49.9	"	+ 0.5	51.0	117.8	87.05	.9974
"	49.6	"	+ 0.5	50.7	117.1	86.78	.9943
"	49.0	"	+ 0.5	50.1	115.7	86.27	.9884
"	48.5	"	+ 0.5	49.6	114.5	85.82	.9833
"	47.0	"	+ 0.5	48.1	111.1	84.54	.9686
"	46.0	"	+ 0.5	47.1	108.8	83.62	.9581
"	43.9	"	+ 0.4	44.9	103.7	81.63	.9353
"	42.0	"	+ 0.4	43.0	99.3	79.92	.9157
"	39.0	+ 0.3	+ 0.4	39.7	91.7	76.80	.8799
"	33.5	+ 0.1	+ 0.3	33.9	78.3	71.97	.8246
"	30.0	+ 0.1	+ 0.3	30.4	70.2	67.20	.7699
"	23.0	+ 0.1	+ 0.2	23.3	53.8	(58.83)	*
"	18.0	0	+ 0.2	18.2	42.0	(51.98)	*
"	50.5	+ 0.6	+ 0.5	51.6	119.1	87.53	1.0029
"	50.1	"	+ 0.5	51.2	118.2	87.20	.9991
"	50.5	"	+ 0.5	51.6	119.1	87.53	1.0029
"	50.5	"	+ 0.5	51.6	119.1	87.53	1.0029
"	50.0	"	+ 0.5	51.1	118.0	87.12	.9982
"	50.0	"	+ 0.5	51.1	118.0	87.12	.9982
"	50.0	"	+ 0.5	51.1	118.0	87.12	.9982
"	50.0	"	+ 0.5	51.1	118.0	87.12	.9982
"	50.0	"	+ 0.5	51.1	118.0	87.12	.9982
"	49.5	"	+ 0.5	50.6	116.8	86.68	.9931
"	48.9	"	+ 0 5	50.0	115.6	86.19	.9875
"	47.0	"	+ 0.5	48.1	111.1	84.54	.9686
"	45.5	"	+ 0.5	46.6	107.6	83.19	.9531
"	43.5	"	+ 0.4	44.5	102.7	81.28	.9313
"	41.0	"	+ 0.4	42.0	97.0	78.99	.9050
"	38.0	+ 0.3	+ 0.4	38.7	89.4	75.83	.8688
"	33.9	+ 0.1	+ 0.3	34.3	79.2	71.38	.8178
"	28.9	+ 0.1	+ 0.3	29.3	67.7	65.99	.7561
"	25.3	+ 0.1	+ 0.3	25.7	59.3	(61.76)	*
"	19.0	0	+ 0.2	19.2	44.3	(53.38)	*
"	13.0	0	+ 0.1	13.1	30.3	(44.15)	*
"	5.0	0	+ 0.1	5.1	11.8	(27.55)	*

Add .011 to scale reading to get distance from center.

* Possibly point was not fully immersed in jet all the time.

the curves of Fig. 62, and thus by this method obtain a value for the co-efficient of discharge of that nozzle.

Take the curve for nozzle *E*, as that happens to be the one for which the full notes are given.

Integrating the total retardation by dividing the whole cross-section into concentric rings, we deduce as follows:

Outer Radius of Ring. (Proportional.)	Width of Ring.	Proportional Area of Ring to Area of Whole Circle.	Per Cent. which Velocity in Ring is Less than Velocity at Center.	Per Cent. by which Retardation Reduces Whole Discharge.
.55	.3025	.3025	0	0
.65	.4225	.1200	.002	.0002
.75	.5625	.1400	.002	.0003
.80	.6400	.0775	.003	.0002
.85	.7225	.0825	.008	.0007
.90	.8100	.0875	.025	.0022
.925	.8556	.0456	.062	.0028
.95	.9025	.0469	.095	.0045
.975	.9506	.0481	.159	.0077
1.00	1.0000	.0494	.232	.0115
Total.....	.....	.....	.....	.0301

This is proportional retardation of whole stream.

Therefore whole volume of water discharged averages flowing with 0.970 of the velocity at center, or if velocity at center is equal to the theoretical velocity due to the head, as supposed on page 415, then we have co-efficient of discharge = .970, while co-efficient actually found by measurement in tank was .971.

The velocity at center was found to be $\frac{0.77}{87.97} = .009$ less for this particular nozzle, however, than velocity due to head measured at base of play-pipe, which difference may have been in part due to slight error in gauge at base of play-pipe.

Thus we see it established that co-efficient of our instrument for measuring velocity is 1.00 within less than 1 per cent. and very likely within less than $\frac{1}{4}$ of 1 per cent.

A more delicate instrument than this modification of Pitot's tube for measuring very high velocities in water can hardly be desired.

In closing the account of these experiments it is but proper that the writer should record his appreciation of the painstaking care and great interest shown in all this work by his assistants, Mr. H. P. Barr and Mr. Benjamin G. Buttolph.

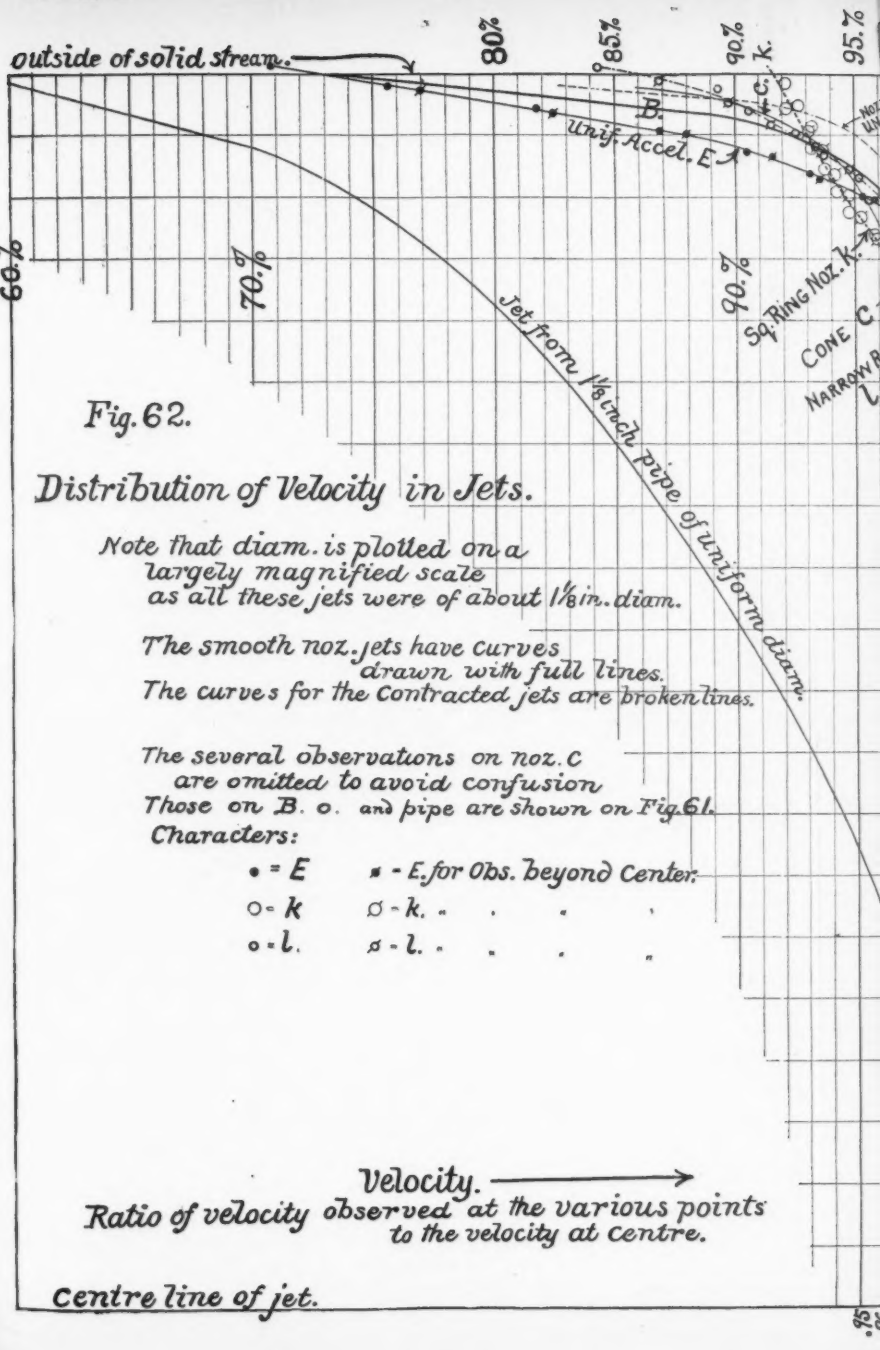


Fig. 62.

Distribution of Velocity in Jets.

Note that diam. is plotted on a largely magnified scale as all these jets were of about 1/8 in. diam.

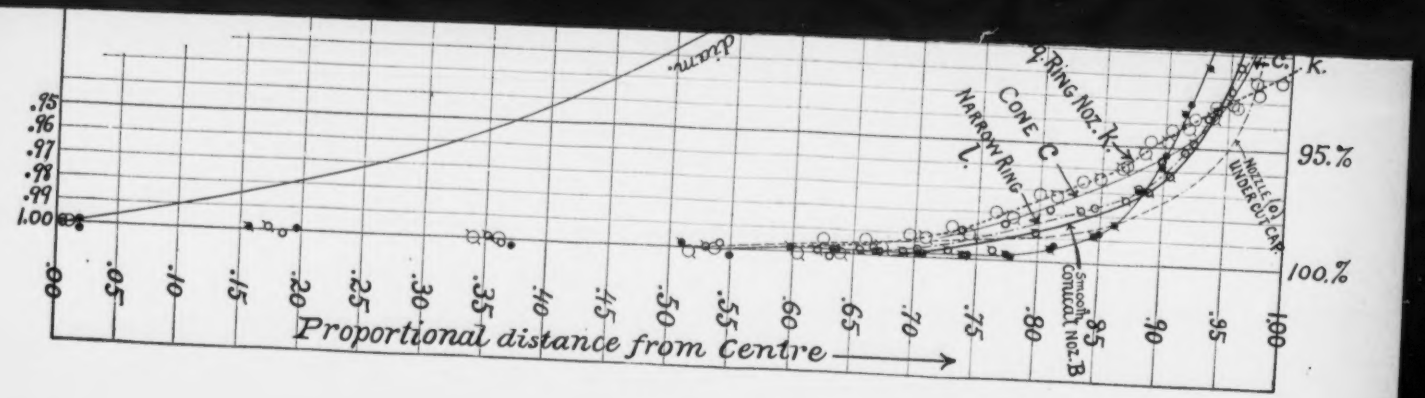
The smooth noz. jets have curves drawn with full lines.
The curves for the contracted jets are broken lines.

The several observations on noz. C are omitted to avoid confusion
Those on B. o. and pipe are shown on Fig. 61.
Characters:

• = E	⁎ - E. for Obs. beyond Center.
○ - K	⊘ - k. " . . "
○ - l.	⌀ - l. " . . . "

Velocity. ⟶
Ratio of velocity observed at the various points to the velocity at centre.

Centre line of jet.


.95
.96
.97
.98
.99
1.00
.00
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
.55
.60
.65
.70
.75
.80
.85
.90
.95
1.00
Proportional distance from Centre
Diam.
Q. RING NOZ. K.
CONE C
NARROW RING L.
SMOOTH CONICAL NOZ. B
NOZZLE (O) UNDER CUT CAP.
K.
95.%
100.%

Practical Tables.

That experiments like the foregoing must be reduced to form convenient for practical use before they can be of much, if any, value to the profession at large, is illustrated by the popularity of the handy Ellis tables, already referred to, and their frequent repetition in the note-books published by pump makers, etc.; while the more accurate though far less convenient formulas for discharge of nozzles presented by Mr. Weston, in his paper before this Society, have been much less used. The writer, therefore, in the effort to make his results as useful as possible, has prepared the following tables giving the practical results of his experiments.

Notes on the Tables for Practical Use.

Table A, pages 422 to 441.—This is the most complete of the tables given relative to fire streams; but it is not in quite so convenient form, however, for the regular use of an insurance inspector, mill superintendent or fire engineer in testing the capacity of a fire pump or the delivery from water works as Table B, pages 444 to 447, which has been prepared for that special purpose.

It will be noted that in the first column the pressure is called "indicated pressure," meaning by this that it was the pressure which gauge attached to a proper piezometer on a hose or pipe $2\frac{1}{2}$ inches in diameter would indicate while the stream was flowing. Nearly, if not all, other authors have based their tables upon the hydrostatic pressure, which, of course, equals the indicated pressure plus an allowance for mean velocity of current past piezometer. Thus, for instance, the indicated pressure of 50 pounds, given in the bold type of the first column of following table for $1\frac{1}{8}$-inch smooth nozzle, corresponds to an effective pressure of 52.1 pounds as given by Ellis, Weston or Box. I adopted the indicated pressure as the main basis of the table because of its greater convenience for use by the practical fire engineer or mechanic. The hydrostatic pressure is, of course, the more scientific unit, and therefore this also is given in finer type in the second column of table.

The third and fifth columns of Table A give the maximum limit of height and distance as a "good effective fire stream." For very favorable conditions with still air the stream would be in condition to do very fair execution at a considerably greater distance, as implied in

notes in margin of column; but in fixing this limit as a good effective stream it was intended that the figure given should be low enough so that it could be safely relied upon as a good stiff stream out to this point under almost any practical conditions—such, for instance, as when a fresh breeze was blowing.

As already stated (page 378) I classed as "good" a stream which, at the limit named, would enter through a window and barely strike ceiling of room with force enough to spatter well, and which at this limit named had not lost its continuity and solidity of stream by dividing into a mere shower of spray. In fixing this extreme horizontal distance reached by a jet as a good effective fire stream, the jet itself is not supposed to be horizontal, but inclined upward an ordinary working angle of about 30 to 45 degrees. In other words, with, for instance, a $1\frac{1}{8}$-inch nozzle and with pressure at nozzle of 40 pounds, the stream would reach, in excellent condition, a third-story window of a building 59 feet distant from end of nozzle.

The Jet Diagram, Fig. 63, gives this information as to reach of $1\frac{1}{8}$-inch jet in very convenient form.

As to number of gallons per minute discharged, this quantity as given in the table is probably exactly correct within less than a single gallon for the exact size and pressure stated. Reference to the previous description in detail may be had as showing that with any ordinary varieties of smooth form of taper or finish of nozzle or play-pipe the variation in form or finish will lead to no error of practical importance; but it must be borne in mind that a difference of $\frac{1}{100}$ of an inch in diameter of orifice of nozzle makes a little more than 2 per cent. difference in its discharge. In computing this part of table the value assumed for co-efficient discharge was 0.974.

There is a great difference in the conducting quality of different kinds of hose, even of the same size (see Fig. 47), and therefore there are given in each table values for pressure required at hydrant or steam fire engine corresponding to each of three different kinds of hose, these values covering about the whole range ordinarily met in practice. The two varieties of rubber hose referred to in the tables are respectively the roughest and the smoothest, or the best and the poorest in conducting power which are usually met in practice, and are the same as shown in *D* and *K*, Fig. 47. Intermediate values can be readily interpolated for other grades of hose between those given in the table. The values

for hydrant pressure given in the table include an allowance for the ordinary crookedness of lines of hose, and an allowance also for the effect upon friction loss in the hose of the ordinary slight excess of the commercial over the nominal diameter. As a basis for computing in these tables the pressure lost in going through hose, the following values were adopted for pounds pressure lost per 100 feet of hose with 240 gallons per minute flowing.

For linen hose,	2½	inch. nom. diam.,		30.0	pounds per 100 feet.
Inferior,	2½	"	rubber lined hose,	26.0	" "
Best,	2½	"	" " "	13.0	" "

These values include allowance for ordinary curves and for ordinary slight excess of actual over nominal diameter.

The loss of pressure was assumed to vary directly as the square of the quantity; a hypothesis shown admissible by a comparison of the dotted lines with the full lines in Fig. 48.

There is also included an allowance for the small loss of pressure in head of hydrant where water enters the hose. This, in computing table, was assumed to be double the theoretical head necessary to produce this velocity in a 2½-inch coupling; this being the ratio actually found by the writer in a series of experiments upon a Chapman Valve Co.'s independent gate hydrant.

Thus the hydrant pressures in the twenty-seven columns at the right-hand side of each sheet of Table A are those which would be found by a gauge attached as shown in sketch on Table B.

¾-INCH SMOOTH

This Table may also be

Hydrant Pressure Required — Discharge

INDICATED PRESSURE by Gauge attached at Base of Play-Pipe, and set level with End of Nozzle		Effective or Static Pressure at Base of Play-Pipe.	Extreme Height of Jet.		Extreme Horizontal Distance reached by Jet.		Gallons per Minute Discharged.	Pounds Pressure Required at Hydrant (or first column, through								
			Average of Highest Drops, Vertical Jet, Still Air.	Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind.	Average Extreme Drops at level of Nozzle, with Still Air.	Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind.		Length 50 ft.			Length 100 ft.			Length 200 ft.		
								Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
	lbs.	lbs.	ft.	ft.	ft.	ft.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Feeble Streams.	5.	5.0	10	.....	18	.....	37	5	5	5	6	6	5	6	6	6
	10.	10.1	20	17	36	19	52	11	11	10	12	11	11	13	13	11
	15.	15.1	30	25	54	24	64	16	16	16	17	17	16	19	19	17
	20.	20.2	40	33	72	29	73	22	22	21	23	23	22	26	25	23
Ordinary Fire Pressures.	25.	25.2	50	41	86	33	82	27	27	26	29	28	27	32	31	28
	30.	30.2	59	48	96	37	90	33	32	31	35	34	32	39	38	34
	35.	35.3	69	55	105	41	97	38	38	37	40	40	38	45	44	40
	40.	40.3	78	60	112	44	104	43	43	42	46	46	43	52	50	46
	45.	45.4	86	64	119	47	110	49	48	47	52	51	48	58	57	51
	50.	50.4	93	67	125	50	116	54	54	52	58	57	54	65	63	57
	55.	55.5	99	70	131	52	122	60	59	58	64	63	59	71	69	63
	60.	60.5	104	72	136	54	127	65	65	63	69	68	65	78	76	68
Unusually High Pressures.	65.	65.5	109	74	141	56	132	71	70	68	75	74	70	84	82	74
	70.	70.6	114	76	145	58	137	76	75	73	81	80	75	91	88	80
	75.	75.6	119	78	149	60	142	81	81	79	87	85	81	97	94	85
	80.	80.7	123	79	153	62	147	87	86	84	93	91	86	104	101	91
	85.	85.7	126	80	157	64	151	92	92	89	98	97	92	110	107	97
	90.	90.7	129	81	161	65	156	98	97	94	104	102	97	117	113	102
	95.	95.8	132	82	164	66	160	103	102	99	110	108	102	123	120	108
	100.	100.8	134	83	167	68	164	109	108	105	116	114	108	130	126	114

Feeble Streams. Ordinary Fire Pressures. Unusually High Pressures.

Maximum: is about 10 per cent. higher; is about 15 per cent. farther; fire stream" limit as a "fair fire stream" limit as a "fair

80 pounds per square inch is now considered best hydrant pressure for general use; 100 lbs. per sq. in. should not be exceeded, except occasionally for very high buildings, or lengths of Hose exceeding 300 feet.

If nozzle is much higher or lower than hydrant, allowance for difference of level must be made on hydrant pressure (10 feet in height corresponds to 4.33 lbs. water pressure).

NOZZLE. (This size of Nozzle gives too small a body of water for extinguishing a fire of much size.) used for ⅞-inch Ring Nozzle. —Height and Distance of Jet.

TABLE A.—No. 1. (From experiments of J. R. FREEMAN, 1888.)

Steamer) while stream is flowing, to maintain pressure at base of play-pipe, as per various lengths and kinds of 2½-inch Hose, as below.

Length 300 ft.			Length 400 ft.			Length 500 ft.			Length 600 ft.			Length 800 ft.			L'gth. 1000 ft.		
Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
lbs.	lbs.	lbs.	lbs	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
7	7	6	8	8	6	9	8	7	9	9	7	11	10	8	12	11	8
14	14	12	16	15	13	17	16	13	19	17	14	21	20	15	24	22	16
22	21	18	24	23	19	26	24	20	28	26	21	32	30	23	36	34	24
29	28	24	32	30	25	34	32	26	37	35	28	43	40	30	48	45	32
36	35	30	39	38	31	43	41	33	46	44	35	53	50	38	61	56	41
43	41	36	47	45	38	52	49	40	56	52	41	64	60	45	73	67	49
50	48	42	55	53	44	60	57	46	65	61	48	75	70	53	85	78	57
58	55	48	63	60	50	69	65	53	74	70	55	86	80	60	97	89	65
65	62	54	71	68	57	77	73	59	84	79	62	96	90	68	109	101	73
72	69	60	79	75	63	86	81	66	93	87	69	107	100	75	121	112	81
79	76	66	87	83	69	95	89	73	102	96	76	118	110	83	133	123	89
86	83	72	95	90	76	103	97	79	112	105	83	128	119	90	145	134	97
93	90	78	103	98	82	112	106	86	121	114	90	139	129	98	157	145	106
101	97	84	110	105	88	120	114	92	130	122	97	150	139	105	169	156	114
108	104	90	118	113	94	129	122	99	139	131	104	160	149	113	182	168	122
115	111	96	126	120	101	138	130	106	149	140	111	171	159	120	194	179	130
122	117	102	134	128	107	146	138	112	158	148	117	182	169	128	206	190	138
129	124	108	142	135	113	155	146	119	167	157	124	193	179	135	218	201	146
137	131	114	150	143	120	163	154	125	177	166	131	203	189	143	230	212	154
144	138	120	158	150	126	172	163	132	186	175	138	214	199	150	242	223	163

TAKE NOTICE. — The above is pressure at hydrant head *while stream is flowing*. The corresponding Static Reservoir Pressure, or Fire-pump Pressure, must be greater than hydrant pressure by an amount equal to friction loss between hydrant-head and pump or reservoir.

⅞-INCH SMOOTH

This Table may also be

Hydrant Pressure Required—Discharge

INDICATED PRESSURE by Gauge attached at Base of Play-Pipe, and set level with End of Nozzle		Effective or Static Pressure at Base of Play-Pipe.	Extreme Height of Jet. Average of Highest Drops, Vertical Jet, Still Air.	Extreme Height of Jet. Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind.	Extreme Horizontal Distance reached by Jet. Average Extreme Drops at level of Nozzle, with Still Air.	Extreme Horizontal Distance reached by Jet. Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind.	Gallons per Minute Discharged.	Pounds Pressure Required at Hydrant (or first column, through Length 50 ft. Unlined Linen Hose.	Length 50 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 50 ft. Ordinary best quality Rubber lined Hose.—Inside Smooth.	Length 100 ft. Unlined Linen Hose.	Length 100 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 100 ft. Ordinary best quality Rubber lined Hose.—Inside Smooth.	Length 200 ft. Unlined Linen Hose.	Length 200 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 200 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.
	lbs.	lbs.	ft.	ft.	ft.	ft.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Feeble Streams.	5.	5.1	11	.....	18	.....	50	6	6	5	6	6	6	8	7	6
	10.	10.2	21	18	37	21	71	12	11	11	13	13	11	16	15	13
	15.	15.2	31	26	56	27	87	17	17	16	19	19	17	23	22	19
	20.	20.3	41	34	74	33	100	23	23	22	26	25	23	31	30	25
Ordinary Fire Pressures.	25.	25.4	51	42	90	38	112	29	29	27	32	31	29	39	37	31
	30.	30.5	61	49	103	42	123	35	34	33	39	38	34	47	45	38
	35.	35.5	71	56	114	46	133	41	40	38	45	44	40	54	52	44
	40.	40.6	81	62	124	49	142	46	46	43	52	50	46	62	59	50
	45.	45.7	89	67	132	52	150	52	51	49	58	57	51	70	67	57
	50.	50.8	97	71	140	55	159	58	57	54	65	63	57	78	74	63
	55.	55.8	105	74	147	58	166	64	63	60	71	69	63	85	82	69
	60.	60.9	112	77	153	61	174	70	69	65	78	75	69	93	89	75
Unusually High Pressures.	65.	66.0	118	79	158	64	181	75	74	71	84	82	74	101	96	82
	70.	71.0	123	81	163	66	188	81	80	76	90	88	80	109	104	88
	75.	76.1	128	83	168	68	194	87	86	82	97	94	86	117	111	94
	80.	81.2	132	85	172	70	201	93	91	87	103	101	91	124	119	101
	85.	86.3	136	87	176	72	207	99	97	92	110	107	97	132	126	107
	90.	91.3	139	88	180	74	213	104	103	98	116	113	103	140	134	113
	95.	96.4	142	89	183	75	219	110	109	103	123	119	109	148	141	119
	100.	101.5	144	90	186	76	224	116	114	109	129	126	114	155	148	126

Feeble Streams. Ordinary Fire Pressures. Unusually High Pressures.

Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind. — Feeble Streams: ..... cent. higher. Ordinary Fire Pressures: is about 10 per cent. higher than "fire stream" limit as a "fair" Maximum

Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind. — Feeble Streams: ..... cent. farther. Ordinary Fire Pressures: is about 12 per cent. farther than "fire stream" limit as a "fair" Maximum

80 pounds per square inch is now considered best hydrant pressure for general use; 100 lbs. per sq. in. should not be exceeded, except occasionally for very high buildings, or lengths of Hose exceeding 300 feet.

If nozzle is much higher or lower than hydrant, allowance for difference of level must be made on hydrant pressure (10 feet in height corresponds to 4.33 lbs. water pressure).

NOZZLE.

used for 1-inch Ring Nozzle.

—Height and Distance of Jet.

TABLE A.—No. 2.
(From experiments of J. R. FREEMAN, 1888.)

Steamer) while stream is flowing, to maintain pressure at base of play-pipe, as per various lengths and kinds of 2½-inch Hose, as below.

Length 300 ft.			Length 400 ft.			Length 500 ft.			Length 600 ft.			Length 800 ft.			L'gth. 1000 ft.		
Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
9	9	7	10	10	7	12	11	8	13	12	9	16	14	10	18	17	11
18	17	14	21	19	15	23	22	16	26	24	17	31	28	19	37	33	22
27	26	21	31	29	22	35	33	24	39	36	26	47	43	29	55	50	33
36	34	27	42	39	30	47	43	32	52	48	34	63	57	39	73	66	43
45	43	34	52	48	37	59	54	40	65	60	43	78	71	48	91	83	54
54	51	41	62	58	45	70	65	48	78	72	51	94	85	58	110	99	65
64	60	48	73	68	52	82	76	56	91	84	60	109	100	68	128	116	76
73	68	55	83	78	59	94	87	64	104	96	68	125	114	78	146	132	87
82	77	62	94	87	67	105	97	72	117	108	77	141	128	87	164	149	97
91	86	69	104	97	74	117	108	80	130	120	86	156	142	97	183	165	108
100	94	75	114	107	82	129	119	88	143	132	94	172	157	107	201	182	119
109	103	82	125	116	89	140	130	96	156	144	103	188	171	116	219	198	130
118	111	89	135	126	96	152	141	104	169	156	111	203	185	126	237	215	141
127	120	96	145	136	104	164	152	112	182	167	120	219	199	136	255	231	152
136	128	103	156	145	111	175	162	120	195	179	128	234	213	145	....	248	162
145	137	110	166	155	119	187	173	128	208	191	137	250	228	155	....	264	173
154	145	116	177	165	126	199	184	136	221	203	145	....	242	165	....	....	184
163	154	123	187	174	134	211	195	144	234	215	154	....	256	174	....	....	195
173	163	130	197	184	141	222	206	152	247	227	163	....	....	184	....	....	206
182	171	137	208	194	148	234	216	160	260	239	171	....	....	194	....	....	216

TAKE NOTICE. — The above is pressure at hydrant head *while stream is flowing*. The corresponding Static Reservoir Pressure, or Fire-pump Pressure, must be greater than hydrant pressure by an amount equal to friction loss between hydrant-head and pump or reservoir.

1-INCH SMOOTH

Hydrant Pressure Required—Discharge

INDICATED PRESSURE by Gauge attached at Base of Play-Pipe, and set level with End of Nozzle.		Effective or Static Pressure at Base of Play-Pipe.	Extreme Height of Jet. Average of Highest Drops, Vertical Jet, Still Air.	Extreme Height of Jet. Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind.	Extreme Horizontal Distance reached by Jet. Average Extreme Drops at level of Nozzle, with Still Air.	Extreme Horizontal Distance reached by Jet. Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind.	Gallons per Minute Discharged.	Pounds Pressure Required at Hydrant (or first column, through								
								Length 50 ft.			Length 100 ft.			Length 200 ft.		
								Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
		lbs.	lbs.	ft.	ft.	ft.	ft.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Feeble Streams.	5.		5.1	10	....	17	....	66	6	6	6	8	7	6	10	9	7
	10.		10.3	21	18	38	21	93	13	12	12	15	14	12	20	18	14
	15.		15.4	32	26	58	30	114	19	19	17	23	22	19	29	27	22
	20.		20.5	43	35	77	37	132	26	25	23	30	29	25	39	37	29
Ordinary Fire Streams. Fair.	25.		25.6	53	43	94	42	147	32	31	29	38	36	31	49	46	36
	30.		30.8	63	51	109	47	161	38	37	34	45	43	37	59	55	43
Good.	35.		35.9	73	58	122	51	174	45	44	40	53	51	44	68	64	51
	40.		41.0	83	64	133	55	186	51	50	46	60	58	50	78	73	58
	45.		46.2	92	69	143	58	198	57	56	52	68	65	56	88	83	65
Excellent.	50.		51.3	101	73	152	61	208	64	62	57	75	72	62	98	92	72
	55.		56.4	109	76	160	64	218	70	69	63	83	79	69	108	101	79
	60.		61.5	117	79	167	67	228	77	75	69	90	87	75	117	110	87
Unusually Strong Streams. (Difficult to hold Nozzle without special appliances.)	65.		66.7	124	82	173	70	237	83	81	75	98	94	81	127	119	94
	70.		71.8	130	85	179	72	246	89	87	80	105	101	87	137	128	101
	75.		76.9	135	87	184	74	255	96	94	86	113	108	94	147	138	108
	80.		82.1	140	89	189	76	263	102	100	92	120	115	100	156	147	115
	85.		87.2	144	91	193	78	274	109	106	98	128	123	106	166	156	123
	90.		92.3	147	92	197	80	279	115	112	103	135	130	112	176	165	130
	95.		97.4	150	94	201	82	287	121	118	109	143	137	118	186	174	137
	100.		102.6	152	96	205	83	295	128	125	115	150	144	125	195	183	144

80 pounds per square inch is now considered best hydrant pressure for general use; 100 lbs. per sq. in. should not be exceeded, except occasionally for very high buildings, or lengths of Hose exceeding 300 feet.

If nozzle is much higher or lower than hydrant, allowance for difference of level must be made on hydrant pressure (10 feet in height corresponds to 4.33 lbs. water pressure).

NOZZLE.
—Height and Distance of Jet.

TABLE A.—No. 3.
(From experiments of J. R. FREEMAN, 1888.)

Steamer) while stream is flowing, to maintain pressure at base of play-pipe, as per various lengths and kinds of 2½-inch Hose, as below.

Length 300 ft.			Length 400 ft.			Length 500 ft.			Length 600 ft.			Length 800 ft.			L'gth. 1000 ft.		
Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
12	11	8	14	13	9	17	15	10	19	17	11	23	21	13	28	25	15
24	22	16	29	26	18	33	30	20	38	34	22	47	42	26	56	50	30
36	33	25	43	39	28	50	45	30	57	51	33	70	63	39	84	75	45
48	45	33	57	52	37	66	60	41	75	68	45	93	84	52	111	99	60
60	56	41	71	65	46	83	75	51	94	85	56	117	105	65	139	124	75
72	67	49	86	79	55	99	90	61	113	102	67	140	125	79	167	149	90
84	78	57	100	92	64	116	105	71	132	119	78	163	146	92	195	174	105
96	89	66	114	105	73	132	120	81	151	136	89	187	167	105	223	199	120
108	100	74	129	118	83	149	135	91	169	153	100	210	188	118	251	223	135
120	111	82	143	131	92	166	151	102	188	170	111	233	209	131	....	248	151
132	122	90	157	144	101	182	166	112	207	187	122	....	230	144	....	....	166
144	134	98	171	157	110	199	181	122	226	204	134	....	251	157	....	....	181
156	145	107	186	170	119	215	196	132	244	221	145	....	....	170	....	....	196
168	156	115	200	183	128	232	211	142	....	238	156	....	....	183	....	....	211
181	167	123	214	196	138	248	226	152	....	255	167	....	....	196	....	....	226
193	178	131	229	209	147	....	241	162	....	....	178	....	....	209	....	....	241
205	189	139	243	222	156	....	256	173	....	....	189	....	....	222	....	....	....
217	200	147	257	236	165	....	....	183	....	....	200	....	....	236	....	....	....
229	211	156	....	249	174	....	....	193	....	....	211	....	....	249	....	....	....
241	223	164	....	....	183	....	....	203	....	....	223	....	....	....	....	....	....

TAKE NOTICE.—The above is pressure at hydrant head *while stream is flowing.* The corresponding Static Reservoir Pressure, or Fire-pump Pressure, must be greater than hydrant pressure by an amount equal to friction loss between hydrant-head and pump or reservoir.

1⅛-INCH SMOOTH
Hydrant Pressure Required—Discharge

INDICATED PRESSURE by Gauge attached at Base of Play-Pipe, and set level with End of Nozzle.		Effective or Static Pressure at Base of Play-Pipe.	Extreme Height of Jet. Average of Highest Drops, Vertical Jet, Still Air	Extreme Height of Jet. Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind.	Extreme Horizontal Distance reached by Jet. Average Extreme Drops at level or Nozzle, with Still Air.	Extreme Horizontal Distance reached by Jet. Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind.	Gallons per Minute Discharged.	Pounds Pressure Required at Hydrant (or first column, through Length 50 ft. Unlined Linen Hose.	Length 50 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 50 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Length 100 ft. Unlined Linen Hose.	Length 100 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 100 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Length 200 ft. Unlined Linen Hose.	Length 200 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 200 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.
		lbs.	ft.	ft.	ft.	ft.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Feeble Streams.		5.	5.2	11	.....	19	.....	84	7	7	6	9	9	7	13	12	9
		10.	10.4	22	18	39	22	119	15	14	12	18	17	14	26	24	17
		15.	15.6	32	27	59	31	146	22	21	19	27	26	21	38	35	26
		20.	20.8	43	36	80	38	168	29	28	25	36	34	28	51	47	34
Ordinary Fire Streams.	Fair.	25.	26.0	54	44	99	44	188	36	35	31	45	43	35	64	59	43
		30.	31.2	64	52	115	50	206	44	42	37	55	52	42	77	71	52
	Good.	35.	36.4	74	59	130	54	222	51	49	43	64	60	49	89	82	60
		40.	41.7	84	65	142	59	238	58	56	50	73	69	56	102	94	69
		45.	46.9	94	70	152	63	252	65	63	56	82	77	63	115	106	77
	Excellent.	50.	52.1	104	75	162	66	266	72	70	62	91	86	70	128	118	86
		55.	57.3	113	80	170	69	279	80	77	68	100	95	77	140	130	95
		60.	62.5	122	83	178	72	291	87	84	74	109	103	84	153	141	103
Unusually Strong Streams. (Difficult to hold Nozzle without special appliances.)		65.	67.7	130	86	185	75	303	94	91	81	118	112	91	166	153	112
		70.	72.9	136	88	191	77	314	101	98	87	127	120	98	179	165	120
		75.	78.1	142	90	197	79	325	109	105	93	136	129	105	191	177	129
		80.	83.3	146	92	203	81	336	116	112	99	145	138	112	204	188	138
		85.	88.5	150	94	209	83	346	123	119	106	154	146	119	217	200	146
		90.	93.7	153	96	214	85	356	130	126	112	164	155	126	230	212	155
		95.	98.9	156	98	219	87	366	138	133	118	173	163	133	242	224	163
		100.	104.1	158	99	224	89	376	145	140	124	182	172	140	255	236	172

Fair. Good. Excellent. — Maximum limit as a "fair stream" is about 10 per cent. higher. Maximum limit as a "fair stream" is about 12 per cent. farther. Maximum limit as a "fair stream" is about 15 per cent. farther.

80 pounds per square inch is now considered best hydrant pressure for general use; 100 lbs. per sq. in. should not be exceeded, except occasionally for very high buildings, or lengths of Hose exceeding 300 feet.

If nozzle is much higher or lower than hydrant, allowance for difference of level must be made on hydrant pressure (10 feet in height corresponds to 4.33 lbs. water pressure).

NOZZLE. (This is the size preferred for general outside use.) —Height and Distance of Jet.

TABLE A.—No. 4. (From experiments of J. R. FREEMAN, 1888.)

Steamer) while stream is flowing, to maintain pressure at base of play-pipe, as per various lengths and kinds of 2½-inch Hose, as below.

Length 300 ft.			Length 400 ft.			Length 500 ft.			Length 600 ft.			Length 800 ft.			L'gth. 1000 ft.		
Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	.os.
16	15	10	20	18	12	24	21	13	28	25	15	35	31	18	42	37	21
33	30	20	40	36	24	48	43	27	55	49	30	70	62	36	84	75	43
49	45	31	60	54	35	71	64	40	82	74	45	105	93	54	127	112	64
66	60	41	80	73	47	95	85	54	110	98	60	139	123	73	168	149	85
82	75	51	101	91	59	119	107	67	137	123	75	174	154	91	211	186	107
99	90	61	121	109	71	143	128	80	165	147	90	209	185	109	253	223	128
115	105	71	141	127	82	166	149	94	192	172	105	243	216	127	....	261	149
131	120	81	161	145	94	190	171	107	220	196	120	278	247	145	....	....	171
148	135	92	181	163	106	214	192	120	247	221	135	.. .	278	163	....	....	192
164	150	102	201	181	118	238	213	134	274	245	150	...	....	181	....	....	213
181	165	112	221	200	130	262	235	147	....	270	165	....	....	200	....	....	235
197	180	122	241	218	141	....	256	160	....	....	180	....	....	218	....	....	256
214	195	132	261	236	153	....	....	174	....	....	195	....	. ..	236	....	....	....
230	209	143	....	254	165	....	....	187	....	....	209	....	....	254	....	....	....
246	224	153	....	.. .	177	....	....	201	....	....	224	....	....	....	....	....	....
263	239	163	....	....	188	....	....	214	..	....	239	....	....	....	....	....	....
....	254	173	....	....	200	.. .	....	227	....	...	254	....	....	....	....	....	....
....	....	183	...	....	212	....	. ..	241	....	....	....	....	....	....	....	....	....
....	....	194	....	..	224	....	....	254	....	....	....	....	....	....	....	....	....
....	....	204	....	....	236	....	....	....	....	....	....	....	....	....	....	....	....

TAKE NOTICE.—The above is pressure at hydrant head *while stream is flowing*. The corresponding Static Reservoir Pressure, or Fire-pump Pressure, must be greater than hydrant pressure by an amount equal to friction loss between hydrant-head and pump or reservoir.

1¼-INCH SMOOTH

Hydrant Pressure Required—Discharge

INDICATED PRESSURE by Gauge attached at Base of Play-Pipe, and set level with End of Nozzle.		Effective or Static Pressure at Base of Play-Pipe.	Extreme Height of Jet. Average of Highest Drops, Vertical Jet, Still Air.	Extreme Height of Jet. Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind.	Extreme Horizontal Distance reached by Jet. Average Extreme Drops at level of Nozzle, with Still Air.	Extreme Horizontal Distance reached by Jet. Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind.	Gallons per Minute Discharged.	Pounds Pressure Required at Hydrant (or first column, through Length 50 ft. Unlined Linen Hose.	Length 50 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 50 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Length 100 ft. Unlined Linen Hose.	Length 100 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 100 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Length 200 ft. Unlined Linen Hose.	Length 200 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 200 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.
	lbs.	lbs.	ft.	ft.	ft.	ft.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Feeble Streams.	5	5.3	11	.....	19	.....	105	8	8	7	11	11	8	17	15	11
	10.	10.6	22	19	40	22	148	17	16	14	23	21	16	34	31	21
	15.	15.9	33	28	62	32	181	25	24	21	34	32	24	51	47	32
	20.	21.2	44	37	83	40	209	34	32	27	45	42	32	68	62	42
Ordinary Fire Streams. Fair.	25.	26.5	55	46	103	47	234	42	40	34	57	53	40	85	77	53
	30.	31.8	66	53	119	54	256	51	49	41	68	63	49	102	93	63
Good.	35.	37.1	76	60	134	59	277	59	57	48	79	74	57	119	109	74
	40.	42.4	86	67	148	63	296	68	65	55	91	84	65	136	124	84
	45.	47.8	97	72	159	67	314	76	73	62	102	95	73	153	140	95
Excellent.	50.	53.1	107	77	169	70	331	85	81	68	113	106	81	170	155	106
	55.	58.4	117	81	178	73	347	93	89	75	124	116	89	187	170	116
	60.	63.7	126	85	186	76	363	102	97	82	136	127	97	204	186	127
Unusually Strong Streams. (Difficult to hold Nozzle without special appliances.)	65.	69.0	133	88	193	79	377	110	105	89	147	137	105	221	201	137
	70.	74.3	140	91	200	81	392	118	113	96	158	148	113	238	217	148
	75.	79.6	145	93	207	83	405	127	121	103	170	158	121	255	232	158
	80.	84.9	150	95	213	85	419	135	129	110	181	169	129	....	248	169
	85.	90.2	154	97	219	88	432	144	137	116	192	179	137	....	263	179
	90.	95.5	157	99	225	90	444	152	145	123	204	190	145	....	....	190
	95.	100.8	159	100	231	92	456	161	154	130	215	201	154	....	....	201
	100.	106.1	161	101	236	93	468	169	162	137	226	211	162	....	....	211

Maximum 1 ft. fair stream" 1 ft. Maximum 1 ft. fair stream" 1 ft.

80 pounds per square inch is now considered best hydrant pressure for general use; 100 lbs. per sq. in. should not be exceeded, except occasionally for very high buildings, or lengths of Hose exceeding 300 feet.

If nozzle is much higher or lower than hydrant, allowance for difference of level must be made on hydrant pressure (10 feet in height corresponds to 4.33 lbs. water pressure).

NOZZLE. (This size is well adapted for serious fires where water supply is ample and line of hose not too long.) — Height and Distance of Jet.

TABLE A.—No. 5. (From experiments of J. R. FREEMAN, 1888.)

Steamer) while stream is flowing, to maintain pressure at base of play-pipe, as per various lengths and kinds of 2½-inch Hose, as below.

Length 300 ft.			Length 400 ft.			Length 500 ft.			Length 600 ft.			Length 800 ft.			L'gth. 1000 ft.		
Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
23	20	13	28	25	15	34	30	18	40	35	20	51	45	25	63	55	30
46	41	26	57	51	31	68	61	36	80	71	41	103	90	51	125	110	61
68	61	39	85	76	47	102	91	54	120	106	61	154	136	76	188	165	91
91	82	52	114	102	62	137	121	72	159	141	82	205	181	101	251	220	121
114	102	65	142	127	77	171	152	90	199	176	102	256	226	127	....	275	152
136	123	78	171	152	93	205	182	108	239	212	123	....	271	152	....	....	182
159	143	91	199	178	109	239	212	126	279	247	142	....	....	178	....	....	212
182	164	104	227	203	124	273	243	144	....	283	164	....	....	203	....	....	243
205	184	117	256	229	140	....	273	162	....	....	184	....	....	229	....	....	....
227	204	130	....	254	155	....	....	180	....	....	204	....	....	254	....	....	....
249	225	143	....	..	170	....	....	198	....	....	225	....	....	....	....	....	....
....	245	156	....	....	186	....	....	216	....	....	245	....	....	..	....	....	....
....	266	169	....	....	201	....	....	234	....	....	....	....	....	....	....	....	....
....	....	182	....	....	217	....	....	252	....	....	....	....	....	....	....	....	....
....	....	195	....	....	232	....	....	....	....	....	....	....	....	....	....	....	....
....	....	208	....	....	248	....	....	....	....	....	....	....	....	....	....	....	....
....	....	221	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	234	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	247	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	261	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

TAKE NOTICE.—The above is pressure at hydrant head *while stream is flowing.* The corresponding Static Reservoir Pressure, or Fire-pump Pressure, must be greater than hydrant pressure by an amount equal to friction loss between hydrant-head and pump or reservoir.

1⅜-INCH SMOOTH

Hydrant Pressure Required—Discharge

INDICATED PRESSURE by Gauge attached at Base of Play-Pipe, and set level with End of Nozzle.		Effective or Static Pressure at Base of Play-Pipe.	Extreme Height of Jet. Average of Highest Drops, Vertical Jet, Still Air.	Extreme Height of Jet. Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind.	Extreme Horizontal Distance reached by Jet. Average Extreme Drops at level of Nozzle, with Still Air.	Extreme Horizontal Distance reached by Jet. Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind.	Gallons per Minute Discharged.	Pounds Pressure Required at Hydrant (or first column, through Length 50 ft. Unlined Linen Hose.	Length 50 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 50 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Length 100 ft. Unlined Linen Hose.	Length 100 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 100 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Length 200 ft. Unlined Linen Hose.	Length 200 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 200 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.
	lbs.	lbs.	ft.	ft.	ft.	ft.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Feeble Streams.	5.	5.5	12	.....	19	....	128	10	10	8	15	13	10	23	21	13
	10.	10.9	23	20	41	23	182	20	19	16	29	27	19	46	42	27
	15.	16.4	34	29	63	33	222	31	29	23	44	40	29	69	62	40
	20.	21.8	45	38	85	42	257	41	39	31	58	53	39	92	83	53
Ordinary Fire Streams. Fair.	25.	27.3	56	47	106	49	287	51	48	39	73	67	48	115	104	67
	30.	32.7	67	55	123	56	315	61	58	47	87	80	58	139	125	80
	35.	38.2	78	62	138	62	340	71	67	54	102	94	67	162	146	94
Good.	40.	43.7	89	69	152	66	363	82	77	62	116	107	77	185	166	107
	45.	49.1	100	74	164	70	385	92	87	70	131	120	87	208	187	120
Excellent.	50.	54.6	111	79	175	73	406	102	96	78	145	134	96	231	208	134
	55.	60.0	121	83	184	76	426	112	106	86	160	147	106	254	229	147
	60.	65.5	131	87	192	79	445	122	116	93	174	160	116	..	250	160
Unusually Strong Streams. (Difficult to hold Nozzle without special appliances.)	65.	70.9	138	90	200	82	463	133	125	101	189	174	125	....	....	174
	70.	76.4	144	92	207	84	480	143	135	109	203	187	135	....	....	187
	75.	81.9	149	95	214	86	497	153	145	117	218	200	145	....	....	200
	80.	87.3	154	97	220	88	514	163	154	124	232	214	154	....	....	214
	85.	92.8	158	99	226	90	529	174	164	132	247	227	164	....	....	227
	90.	98.2	161	100	232	92	545	184	173	140	261	240	173	....	....	240
	95.	103.7	163	101	238	94	560	194	183	148	....	254	183	....	....	254
	100.	109.1	165	103	243	96	574	204	193	156	....	....	193	....	....	....

Feeble Streams. Average Extreme Drops, Vertical Jet, Still Air. Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind. 20 ft. 29 ft. Average Extreme Drops at level of Nozzle, with Still Air. 41 ft. Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind. 33 ft.

Ordinary Fire Streams. Fair. Good. Excellent. Average Extreme Drops, Vertical Jet, Still Air. 25. 27.3 56 ft. Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind. 47 ft. 106 ft. Average Extreme Drops at level of Nozzle, with Still Air. 49 ft. Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind. 287 lbs. 51 48 39 73 67 48 115 104 67

Unusually Strong Streams. (Difficult to hold Nozzle without special appliances.) Average Extreme Drops, Vertical Jet, Still Air. 65. 70.9 138 ft. Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind. 90 ft. 200 ft. Average Extreme Drops at level of Nozzle, with Still Air. 82 ft. Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind. 463 lbs. 133 125 101 189 174 125 174

80 pounds per square inch is now considered best hydrant pressure for general use; 100 lbs. per sq. in. should not be exceeded, except occasionally for very high buildings, or lengths of Hose exceeding 300 feet.

If nozzle is much higher or lower than hydrant, allowance for difference of level must be made on hydrant pressure (10 feet in height corresponds to 4.33 lbs. water pressure).

NOZZLE.
—Height and Distance of Jet.

TABLE A.—No. 6.
(From experiments of J. R. FREEMAN, 1888.)

Steamer\ while stream is flowing, to maintain pressure at base of play-pipe, as per various lengths and kinds of 2½-inch Hose, as below.

Length 300 ft.			Length 400 ft.			Length 500 ft.			Length 600 ft.			Length 800 ft.			L'gth. 1000 ft.		
Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
32	28	17	40	36	21	49	43	25	57	51	28	74	66	36	92	80	43
63	56	34	81	71	42	98	86	49	115	101	56	149	131	71	184	161	86
95	85	51	121	107	62	147	129	74	172	152	85	224	196	107	275	241	129
127	113	68	161	143	83	195	173	98	230	202	113	299	262	143	....	321	173
158	141	85	201	178	104	244	216	123	287	253	141	....	....	178	....	....	216
190	169	103	242	214	125	293	259	147	....	....	169	....	....	2..4	....	....	259
222	198	120	282	250	146	....	....	172	....	....	198	....	....	250	....	....	....
253	226	137	....	....	166	....	....	196	....	....	226	....	....	....	....	....	....
....	254	154	..	....	187	....	....	221	....	....	254	....	....	....	....	....	....
....	....	171	....	....	208	....	....	245	....	....	....	....	....	....	....	....	....
....	....	188	....	....	229	....	....	270	....	....	....	....	....	....	....	....	....
....	....	205	....	....	250	....	....	....	....	....	....	....	....	....	....	....	....
....	....	222	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	239	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	256	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
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....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

TAKE NOTICE. — The above is pressure at hydrant head *while stream is flowing*. The corresponding Static Reservoir Pressure, or Fire-pump Pressure, must be greater than hydrant pressure by an amount equal to friction loss between hydrant-head and pump or reservoir.

Ring Nozzles.

Although it was conclusively proved by the experiments described above that the ring nozzle does not possess the slightest advantage over the smooth nozzle, yet, so many ring nozzles are in use that it was

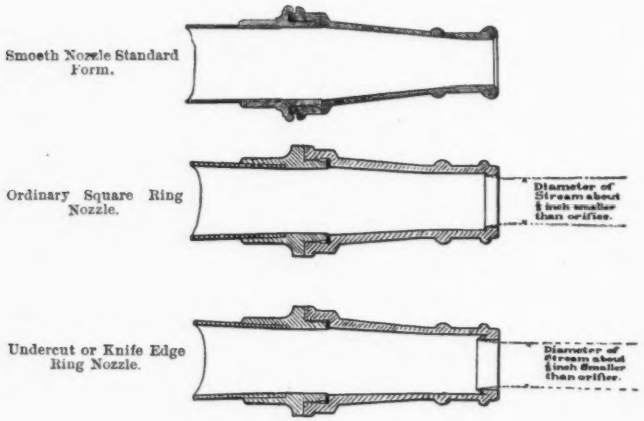

Smooth Nozzle Standard Form.
Ordinary Square Ring Nozzle.
Diameter of Stream about ½ inch smaller than orifice.
Undercut or Knife Edge Ring Nozzle.
Diameter of Stream about ½ inch Smaller than orifice.

Fig. 59.—Ring Nozzles.

thought best to prepare tables giving their discharge. Drawings of the three kinds of nozzles are repeated above for ready reference. The experiments previously described (see page 334) show that the ring nozzle discharges only three-fourths as much water per minute as the smooth nozzle of the same size, and if any one will measure the diameter of the jet at about one-half inch from end of nozzle by a pair of common machinist's calipers, he will find it to be about $\frac{1}{8}$ inch smaller than the hole from which it issues. Thus the only use of the ring nozzle is to make a show of playing a larger stream than is the fact.

The apparent advantage of the ring nozzle, which has misled many firemen, is easily explained. The result is the same as if a smaller nozzle were used while hydrant pressure remained the same; thus the

number of gallons per minute flowing being less, the pressure lost by friction through hose is less, and therefore there remains a greater pressure at base of play-pipe, and this carries the stream to a somewhat greater height and distance, but with greatly diminished volume. For $\frac{7}{8}$-inch and 1-inch ring nozzles the discharge is almost exactly the same as for smooth nozzle $\frac{1}{8}$ inch smaller. Therefore, no special tables for these two sizes of ring nozzle are given.

As a basis for computing these discharges of ring nozzles the value 0.74 was adopted for co-efficient of discharge.

(Discharge of 1-in. Ring is same as 7/8-in. Smooth.)
(Discharge of 7/8-in. Ring is same as 3/4-in. Smooth.)

1 1/8-INCH RING

Hydrant Pressure Required—Discharge

INDICATED PRESSURE by Gauge attached at Base of Play-Pipe, and set level with End of Nozzle.		Effective or Static Pressure at Base of Play Pipe.	Extreme Height of Jet. Average of Highest Drops, Vertical Jets, Still Air.	Extreme Height of Jet. Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind.	Extreme Horizontal Distance reached by Jet. Average Extreme Drops at level of Nozzle, with Still Air.	Extreme Horizontal Distance reached by Jet. Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind.	Gallons per Minute Discharged.	Pounds Pressure Required at Hydrant (or first column, through Length 50 ft. Unlined Linen Hose.	Length 50 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 50 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Length 100 ft. Unlined Linen Hose.	Length 100 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 100 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Length 200 ft. Unlined Linen Hose.	Length 200 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 200 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.
		lbs.	lbs.	ft.	ft.	ft.	ft.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Feeble Streams.		5.	5.1	10	.....	17	.....	63	6	6	6	7	7	6	9	9	7
		10.	10.2	21	17	37	20	89	13	12	11	15	14	12	19	18	14
		15.	15.4	32	cent. higher. 26	57	cent. farther. 29	110	19	18	17	22	21	18	28	27	21
		20.	20.5	42	34	76	36	126	25	25	23	29	28	25	38	35	28
Ordinary Fire Streams.	Fair.	25.	25.6	52	42	93	41	141	31	31	28	37	35	31	47	44	35
		30.	30.7	62	49	107	45	155	38	37	34	44	42	37	56	53	42
	Good.	35.	35.8	72	56	120	49	167	44	43	40	51	49	43	66	62	49
		40	40.9	82	62	131	53	179	50	49	45	59	56	49	75	71	56
	Excellent.	45.	46.0	91	67	141	56	190	56	55	51	66	63	55	85	80	63
		50.	51.2	99	70	150	59	200	63	61	57	73	70	61	94	88	70
		55.	56.3	107	73	158	62	210	69	67	63	80	77	67	103	97	77
		60.	61.4	115	76	164	65	219	75	74	68	88	84	74	113	106	84
Unusually Strong Streams. (Difficult to hold Nozzle without special appliances.)		65.	66.5	122	79	170	67	228	82	80	74	95	91	80	122	115	91
		70.	71.6	128	82	176	69	237	88	86	80	102	98	86	132	124	98
		75.	76.7	133	84	181	71	245	94	92	85	110	106	92	141	133	106
		80.	81.8	138	86	186	73	253	100	98	91	117	113	98	150	141	113
		85.	87.0	142	Maximum 88	190	Maximum 75	261	107	104	97	124	120	104	160	150	120
		90.	92.1	145	89	194	77	268	113	110	102	132	127	110	169	159	127
		95.	97.2	148	91	198	79	276	119	117	108	139	134	117	179	168	134
		100.	102.3	150	93	202	80	283	125	123	114	146	141	123	188	177	141

NOTE.—The above figures for Ring Nozzle Discharges will apply to any ordinary form of Ring accurately enough for practical purposes, but apply especially to ordinary form of Ring Nozzle with square shoulder $\frac{1}{16}$ or $\frac{1}{8}$ inch deep.

Ring Nozzles with "undercut" or "knife-edge" shoulder, discharge, as ordinarily constructed, about three per cent. less than quantity given above.

NOZZLE.
—Height and Distance of Jet.

TABLE A.—No. 7.
(From experiments of J. R. FREEMAN, 1888.)

Steamer) while stream is flowing, to maintain pressure at base of play-pipe, as per various lengths and kinds of 2½-inch Hose, as below.

Length 300 ft.			Length 400 ft.			Length 500 ft.			Length 600 ft.			Length 800 ft.			L'gth. 1000 ft.		
Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
12	11	8	14	12	9	16	14	10	18	16	11	22	20	12	26	23	14
23	21	16	27	25	18	31	29	19	35	32	21	44	39	25	52	47	29
34	32	24	41	37	27	47	43	29	53	48	32	66	59	37	78	70	43
46	43	32	54	50	35	63	57	39	71	64	43	88	79	50	104	93	57
57	53	40	68	62	44	78	71	49	89	80	53	110	98	62	130	116	71
69	64	48	81	75	53	94	86	58	106	96	64	131	118	75	156	140	86
80	75	56	95	87	62	110	100	68	124	112	75	153	138	87	182	163	100
92	85	64	108	100	71	125	114	78	142	128	85	175	157	100	208	186	114
103	96	71	122	112	80	141	128	88	160	145	96	197	177	112	234	209	128
115	106	79	136	125	88	156	143	97	177	161	106	219	197	125	260	233	143
126	117	87	149	137	97	172	157	107	195	177	117	241	216	137	....	256	157
138	128	95	163	149	106	188	171	117	213	193	128	263	236	149	....	....	171
149	138	103	176	162	115	203	185	127	230	209	138	....	256	162	....	....	185
161	149	111	190	174	124	219	200	136	248	225	149	....	....	174	....	....	200
172	160	119	203	187	132	235	214	146	266	241	160	....	....	187	....	....	214
184	170	127	217	199	141	250	228	156	....	257	170	....	....	199	....	....	228
195	181	135	231	212	150	....	242	166	....	....	181	....	....	212	....	....	242
207	192	143	244	224	159	....	257	175	....	....	192	....	....	224	....	....	257
218	202	151	258	237	168	....	....	185	....	....	202	....	....	237	....	....	....
230	213	159	....	249	177	....	....	195	....	....	213	....	....	249	....	....	....

TAKE NOTICE.—The above is pressure at hydrant head *while stream is flowing*. The corresponding Static Reservoir Pressure, or Fire-pump Pressure, must be greater than hydrant pressure by an amount equal to friction loss between hydrant-head and pump or reservoir.

1¼-INCH RING

Hydrant Pressure Required — Discharge

INDICATED PRESSURE by Gauge attached at Base of Play-Pipe, and set level with End of Nozzle.		Effective or Static Pressure at Base of Play-Pipe.	Extreme Height of Jet.		Extreme Horizontal Distance reached by Jet.		Gallons per Minute Discharged.	Pounds Pressure Required at Hydrant (or first column, through								
			Average of Highest Drops, Vertical Jet, Still Air.	Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind.	Average Extreme Drops at level of Nozzle, with Still Air.	Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind.		Length 50 ft.			Length 100 ft.			Length 200 ft.		
								Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
		lbs.	lbs.	ft.	ft.	ft.	ft.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Feeble Streams.		5.	5.2	11		20		79	7	7	6	9	8	7	12	11	8
		10.	10.4	21	17	39	21	111	14	13	12	17	16	13	24	22	16
		15.	15.5	32	26	58	30	136	21	20	18	26	24	20	35	33	24
		20.	20.7	43	35	78	37	157	28	27	24	34	33	27	47	44	33
Ordinary Fire Streams.	Fair.	25.	25.9	53	43	97	42	176	35	34	30	43	41	34	59	55	41
		30.	31.1	63	49	112	48	192	42	40	36	51	49	40	71	66	49
	Good.	35.	36.2	73	56	126	51	208	49	47	42	60	57	47	82	76	57
		40.	41.4	83	63	138	55	222	56	54	48	69	65	54	94	87	65
		45.	46.6	93	68	149	59	236	63	61	54	77	73	61	106	98	73
	Excellent.	50.	51.8	102	72	157	62	248	70	67	61	86	81	67	118	109	81
		55.	57.0	111	76	164	65	260	77	74	67	94	90	74	130	120	90
		60.	62.1	119	79	172	68	272	84	81	73	103	98	81	141	131	98
Unusually Strong Streams. (Difficult to hold Nozzle without special appliances.)		65.	67.3	127	81	178	71	283	90	88	79	111	106	88	153	142	106
		70.	72.5	133	84	185	73	294	97	94	85	120	114	94	165	153	114
		75.	77.7	138	86	191	75	304	104	101	91	129	122	101	177	164	122
		80.	82.8	143	88	196	77	314	111	108	97	137	130	108	188	175	130
		85.	88.0	147	90	201	79	324	118	115	103	146	138	115	200	186	138
		90.	93.2	149	92	206	81	333	125	121	109	154	147	121	212	197	147
		95.	98.4	152	94	211	82	342	132	128	115	163	155	128	224	208	155
		100.	103.5	154	95	215	84	351	139	135	121	171	163	135	236	218	163

			Extreme Height of Jet.		Extreme Horizontal Distance reached by Jet.			Pounds Pressure Required at Hydrant (or first column, through								
								Length 50 ft.			Length 100 ft.			Length 200 ft.		
			Average of Highest Drops, Vertical Jet, Still Air.	Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind.	Average Extreme Drops at level of Nozzle, with Still Air.	Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind.		Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
INDICATED PRESSURE by Gauge attached at Base of Play-Pipe, and set level with End of Nozzle.		Effective or Static Pressure at Base of Play-Pipe.					Gallons per Minute Discharged.									
		lbs.	ft.	ft.	ft.	ft.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Feeble Streams.		5.	5.2	11		20		79	7	7	6	9	8	7	12	11	8
		10.	10.4	21	17	39	21	111	14	13	12	17	16	13	24	22	16
		15.	15.5	32	26	58	30	136	21	20	18	26	24	20	35	33	24
		20.	20.7	43	35	78	37	157	28	27	24	34	33	27	47	44	33
Ordinary Fire Streams.	Fair.	25.	25.9	53	43	97	42	176	35	34	30	43	41	34	59	55	41
		30.	31.1	63	49	112	48	192	42	40	36	51	49	40	71	66	49
	Good.	35.	36.2	73	56	126	51	208	49	47	42	60	57	47	82	76	57
		40.	41.4	83	63	138	55	222	56	54	48	69	65	54	94	87	65
		45.	46.6	93	68	149	59	236	63	61	54	77	73	61	106	98	73
	Excellent.	50.	51.8	102	72	157	62	248	70	67	61	86	81	67	118	109	81
		55.	57.0	111	76	164	65	260	77	74	67	94	90	74	130	120	90
		60.	62.1	119	79	172	68	272	84	81	73	103	98	81	141	131	98
Unusually Strong Streams. (Difficult to hold Nozzle without special appliances.)		65.	67.3	127	81	178	71	283	90	88	79	111	106	88	153	142	106
		70.	72.5	133	84	185	73	294	97	94	85	120	114	94	165	153	114
		75.	77.7	138	86	191	75	304	104	101	91	129	122	101	177	164	122
		80.	82.8	143	88	196	77	314	111	108	97	137	130	108	188	175	130
		85.	88.0	147	90	201	79	324	118	115	103	146	138	115	200	186	138
		90.	93.2	149	92	206	81	333	125	121	109	154	147	121	212	197	147
		95.	98.4	152	94	211	82	342	132	128	115	163	155	128	224	208	155
		100.	103.5	154	95	215	84	351	139	135	121	171	163	135	236	218	163

NOTE.—The above figures for Ring Nozzle Discharges will apply to any ordinary form of Ring accurately enough for practical purposes, but apply especially to ordinary form of Ring Nozzle with square shoulder $\frac{1}{16}$ or $\frac{1}{8}$ inch deep.

Ring Nozzles with "undercut" or "knife-edge" shoulder, discharge, as ordinarily constructed, about three per cent. less than quantity given above.

NOZZLE.
—Height and Distance of Jet.

TABLE A.—No. 8.
(From experiments of J. R. FREEMAN, 1888.)

Steamer) while stream is flowing, to maintain pressure at base of play-pipe, as per various lengths and kinds of 2½-inch Hose, as below.

Length 300 ft.			Length 400 ft.			Length 500 ft.			Length 600 ft.			Length 800 ft.			L'gth. 1000 ft.		
Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
15	14	10	18	17	11	21	19	12	25	22	14	31	28	17	38	33	19
30	27	19	36	33	22	43	39	25	49	44	27	62	55	33	75	66	39
45	41	29	55	49	33	64	58	37	74	66	41	93	83	49	112	100	58
60	55	38	73	66	44	86	77	49	99	88	55	124	111	66	150	133	77
75	69	48	91	83	55	107	96	62	123	110	69	155	138	83	187	166	96
90	82	57	109	99	66	128	116	74	148	132	82	186	166	99	225	199	116
105	96	67	127	115	76	150	135	86	172	154	96	217	193	115	262	232	135
120	110	76	146	132	87	171	154	99	197	176	110	248	221	132	....	266	154
135	123	86	164	148	98	193	173	111	222	199	123	279	249	148	....	....	173
150	137	95	182	165	109	214	193	123	246	221	137	....	276	165	....	....	193
165	151	105	200	181	120	236	212	135	271	243	151	....	....	181	....	....	212
180	164	114	218	198	131	257	231	148	....	265	164	....	....	198	....	....	231
195	178	124	237	214	142	....	251	160	....	....	178	....	....	214	....	....	251
210	192	133	255	231	153	....	....	172	....	....	192	....	....	231	....	....	....
225	206	143	....	247	164	....	....	185	....	....	206	....	....	247	....	....	....
240	219	152	....	264	175	....	....	197	....	....	219	....	....	264	....	....	....
255	233	162	....	....	186	....	....	209	....	....	233	....	....	....	....	....	....
....	247	172	....	....	197	....	....	222	....	....	247	....	....	....	....	....	....
....	260	181	....	....	208	....	....	234	....	....	260	....	....	....	....	....	....
....	....	191	....	....	218	....	....	246	....	....	....	....	....	....	....	....	....

TAKE NOTICE.—The above is pressure at hydrant head *while stream is flowing*. The corresponding Static Reservoir Pressure, or Fire-pump Pressure, must be greater than hydrant pressure by an amount equal to friction loss between hydrant-head and pump or reservoir.

$1\frac{3}{8}$-INCH RING

Hydrant Pressure Required — Discharge

INDICATED PRESSURE by Gauge attached at Base of Play-Pipe, and set level with End of Nozzle.		Effective or Static Pressure at Base of Play-Pipe.	Extreme Height of Jet. Average of Highest Drops, Vertical Jet, Still Air.	Extreme Height of Jet. Maximum Limit of Height as Good Effective Fire Stream with Moderate Wind.	Extreme Horizontal Distance reached by Jet. Average Extreme Drops at level of Nozzle, with Still Air.	Extreme Horizontal Distance reached by Jet. Maximum Limit of Distance as Good Effective Fire Stream with Moderate Wind.	Gallons per Minute Discharged.	Pounds Pressure Required at Hydrant (or first column, through Length 50 ft. Unlined Linen Hose.	Length 50 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 50 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Length 100 ft. Unlined Linen Hose.	Length 100 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 100 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Length 200 ft. Unlined Linen Hose.	Length 200 ft. Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Length 200 ft. Ordinary best quality Rubber-lined Hose.—Inside Smooth.
	lbs.	lbs.	ft.	ft.	ft.	ft.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Feeble Streams,	5.	5.3	11	....	20	....	96	8	8	7	10	10	8	15	14	10
	10.	10.5	22	17	39	21	136	16	15	13	21	19	15	30	28	19
	15.	15.8	32	27	59	31	166	24	23	20	31	29	23	45	41	29
	20.	21.1	43	36	79	39	192	32	30	26	41	39	30	60	55	39
Ordinary Fire Streams, Fair.	25.	26.3	53	44	99	45	214	40	38	33	52	48	38	75	69	48
	30.	31.6	64	51	116	50	235	48	46	39	62	58	46	91	83	58
	35.	36.8	74	58	131	55	253	55	53	46	72	68	53	106	97	68
Good.	40.	42.1	85	64	144	59	271	63	61	53	82	77	61	121	111	77
	45.	47.4	95	69	154	63	287	71	68	59	93	87	68	136	124	87
	50.	52.6	105	74	164	66	303	79	76	66	103	97	76	151	138	97
	55.	57.9	114	78	172	69	318	87	84	72	113	106	84	166	152	106
Excellent.	60.	63.2	123	81	180	72	332	95	91	79	124	116	91	181	166	116
Unusually Strong Streams, (Difficult to hold Nozzle without special appliances.)	65.	68.4	131	84	187	75	346	103	99	85	134	126	99	196	180	126
	70.	73.7	137	86	194	77	359	111	106	92	144	135	106	211	193	135
	75.	79.0	142	88	200	79	371	119	114	98	155	145	114	226	207	145
	80.	84.2	147	90	206	81	383	127	122	105	165	155	122	241	221	155
	85.	89.5	150	92	212	82	395	135	129	112	175	164	129	257	235	164
	90.	94.7	153	94	217	84	407	143	137	118	186	174	137	....	249	174
	95.	100.0	156	96	222	86	418	150	144	125	196	184	144	....	263	184
	100.	105.3	158	97	227	88	429	158	152	131	206	193	152	....	....	193

Maximum: "fair" limit as a fire stream.

NOTE.— The above figures for Ring Nozzle Discharges will apply to any ordinary form of Ring accurately enough for practical purposes, but apply especially to ordinary form of Ring Nozzle with square shoulder $\frac{1}{16}$ or $\frac{1}{8}$ inch deep.

Ring Nozzles with "undercut" or "knife-edge" shoulder, discharge, as ordinarily constructed, about three per cent. less than quantity given above.

NOZZLE.
—Height and Distance of Jet.

TABLE A.—No. 9.
(From experiments of J. R. FREEMAN, 1888.)

Steamer) while stream is flowing, to maintain pressure at base of play-pipe, as per various lengths and kinds of 2½-inch Hose, as below.

Length 300 ft.			Length 400 ft.			Length 500 ft.			Length 600 ft.			Length 800 ft.			L'gth. 1000 ft.		
Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
20	18	12	25	22	14	29	26	16	34	30	18	44	39	22	53	47	26
40	36	24	49	44	28	59	53	32	68	61	36	88	77	44	107	94	53
60	54	35	74	66	41	88	79	48	103	91	54	131	116	66	160	141	79
79	72	47	99	88	55	118	105	64	137	122	72	175	155	88	213	188	105
99	90	59	123	111	69	147	131	79	171	152	90	219	193	111	267	235	131
119	108	70	148	133	83	177	157	95	205	182	108	263	232	133	....	282	157
139	126	82	173	155	97	206	184	111	240	213	126	....	271	155	....	....	184
159	144	94	197	177	111	236	210	127	274	243	144	....	....	177	....	....	210
179	162	106	222	199	124	265	236	143	....	274	162	....	....	199	....	....	236
199	180	117	247	221	138	....	263	159	....	....	180	....	....	221	....	....	263
219	198	129	271	243	152	....	....	175	....	....	198	....	....	243	....	....	....
238	216	141	....	265	166	....	....	191	....	....	216	....	....	265	....	....	....
258	234	153	....	....	180	....	....	207	....	....	234	....	....	....	....	....	....
....	251	164	....	....	193	....	....	222	....	....	251	....	....	....	....	....	....
....	....	176	....	....	207	....	....	238	....	....	....	....	....	....	....	....	....
....	....	188	....	....	221	....	....	254	....	....	....	....	....	....	....	....	....
....	....	200	....	....	235	....	....	....	....	....	....	....	....	....	....	....	....
....	....	211	....	....	249	....	....	....	....	....	....	....	....	....	....	....	....
....	....	223	....	....	263	....	....	....	....	....	....	....	....	....	....	....	....
....	....	235	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

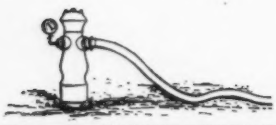
TAKE NOTICE.—The above is pressure at hydrant head ***while stream is flowing.*** The corresponding Static Reservoir Pressure, or Fire-pump Pressure, must be greater than hydrant pressure by an amount equal to friction loss between hydrant-head and pump or reservoir.

Fire Pump Inspection Tables.

Tables B No. 1 and B No. 2 are designed for the convenient use of water-works superintendents in measuring water supplied for filling tanks or other purposes, and are also of much convenience in testing a pump to see if it will throw its rated capacity.

Certain kinds of pumps, particularly rotary piston pumps, so-called, deteriorate rapidly by use or by long standing, and it is one of the regular duties of the insurance inspector or of the prudent mill superintendent to test such pumps from time to time. These tables, B No. 1 and B No. 2, may, by intelligent interpolation, give results certain to within about five per cent., but are not designed for the very accurate gauging of discharge of pumping engines referred to at the beginning of this paper (p. 304 and p. 330). For such work it is necessary to measure the pressure close to the base of play-pipe and will generally be necessary to caliper the diameter of nozzle very exactly, and to make some allowance for velocity of flow past piezometer dependent upon the peculiar conditions which may happen to exist. For such cases, therefore, special computations will generally have to be made. Had time allowed, the writer would have presented some tables containing the elements for making such computations expeditiously. They can, however, be very expeditiously computed by the aid of the very convenient and accurate velocity tables in the "Lowell Hydraulic Experiments."

To return to Tables B No. 1 and B No. 2, somewhat greater accuracy can be obtained with Table B No. 1 using only fifty feet of hose, than with greater lengths. The "Open Butt Table" is of necessity less accurate in its results than the other tables, since small differences in diameter of hose and in smoothness of its interior surface have relatively a very great effect in modifying the discharge. There are, however, very many practical purposes for which such a table is of a great deal of convenience, such, for instance, as in determining the number of gallons per minute which can be supplied at any portion of a water-works distribution system without lowering the pressure below a certain point. And is also of convenient application sometimes for roughly measuring water supplied to fill tanks.



PUMP INSPECTION

Discharge of Nozzles attached

HYDRANT PRESSURE indicated while Stream is flowing by Gauge attached to Hydrant, as shown.	1⅜-Inch Smooth Nozzle. Gals. per Min.			1¼-Inch Smooth Nozzle. Gals. per Min.			1⅛-Inch Smooth Nozzle. Gals. per Min.			1-Inch Smooth Nozzle. Gals. per Min.			⅞-Inch Smooth Nozzle, or 1-Inch Ring Nozzle. Gals. per Min.		
Lbs. per sq. in.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
5	90	92	103	80	82	90	70	71	75	59	59	62	47	47	48
10	127	131	146	114	116	127	99	101	107	83	84	87	66	67	68
15	155	160	179	140	143	154	121	123	131	101	102	106	81	81	84
20	180	185	206	161	164	179	140	142	151	117	118	123	93	94	96
25	201	207	230	180	184	200	156	158	169	131	132	137	104	105	107
30	220	226	251	197	202	219	171	173	184	143	144	150	114	115	118
35	238	245	272	213	218	236	184	188	199	154	156	162	123	124	127
40	255	262	291	227	233	253	197	201	213	165	167	173	132	133	136
45	270	278	309	241	247	269	209	213	226	175	177	184	140	141	144
50	284	293	325	255	260	283	221	224	238	184	186	194	147	148	152
55	298	307	341	267	273	296	232	235	250	193	195	204	154	155	159
60	311	320	357	279	285	309	242	245	261	202	204	213	161	162	167
65	324	333	371	290	296	322	252	255	272	210	213	221	168	169	173
70	336	346	385	301	307	334	261	265	281	218	221	230	174	176	180
75	348	358	399	311	318	344	270	275	291	226	228	238	181	182	186
80	359	370	412	322	329	357	279	284	301	233	236	246	186	188	192
85	371	382	425	332	339	369	288	293	310	240	243	253	192	193	198
90	381	393	437	341	349	379	296	301	319	247	250	261	197	199	204
95	392	403	449	350	358	390	304	309	328	253	257	268	203	204	209
100	402	414	461	359	368	400	312	317	337	260	264	275	208	210	215

Quantities are stated in United States gallons of 231 cubic inches.

TABLES.

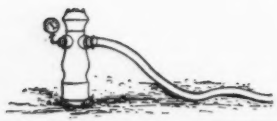
to 50 Feet of 2½-inch Hose.

TABLE B.—No. 1
(From experiments of J. R. FREEMAN, 1888.)

¾-Inch Smooth Nozzle, or ⅞-inch Ring Nozzle. Gals. per Min.			1⅜-Inch Ring Nozzle. Gals. per Min.			1¼-Inch Ring Nozzle. Gals. per Min.			1⅛-Inch Ring Nozzle. Gals. per Min.			HYDRANT PRESSURE.
Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Lbs. per sq. in.
36	36	37	75	76	84	66	67	70	56	56	59	5
50	50	51	108	110	118	94	96	101	80	81	84	10
61	61	62	132	135	144	115	117	124	98	99	103	15
71	71	72	152	155	167	133	135	143	113	114	119	20
79	80	81	170	174	187	149	151	159	126	128	133	25
86	87	88	187	191	205	163	165	175	138	140	145	30
93	93	95	201	206	221	176	179	189	149	151	157	35
100	100	101	215	219	237	188	191	202	159	162	168	40
106	106	108	229	233	251	200	203	214	169	172	178	45
112	112	113	241	245	264	211	214	226	179	181	188	50
117	117	119	253	257	277	221	224	237	187	189	197	55
122	122	124	264	269	289	231	234	247	196	198	205	60
127	127	129	275	280	301	240	244	257	205	206	214	65
132	132	134	285	291	313	249	253	267	212	213	222	70
137	137	139	295	301	324	258	262	276	219	221	230	75
141	142	144	305	311	334	266	270	285	226	228	237	80
145	146	148	314	320	345	274	279	294	233	235	244	85
149	150	152	323	329	355	282	287	303	239	242	252	90
153	154	156	332	338	364	290	295	311	246	249	259	95
158	159	161	340	347	374	298	303	319	253	255	266	100

NOTE.—The above figures for Ring Nozzle Discharges will apply to any ordinary form of Ring accurately enough for practical purposes, but apply especially to ordinary form of Ring Nozzle with square shoulder $\frac{1}{16}$ or $\frac{1}{8}$ inch deep.

Ring Nozzles with "under-cut" or "knife-edge" shoulder, discharge, as ordinarily constructed, about 3 per cent. less than quantity given above.



PUMP INSPECTION

Discharge of Nozzles attached

HYDRANT PRESSURE indicated while Stream is flowing by Gauge attached to Hydrant, as shown.	1⅜-Inch Smooth Nozzle. Gals. per Min.			1¼-Inch Smooth Nozzle. Gals. per Min.			1⅛-Inch Smooth Nozzle. Gals. per Min.			1-Inch Smooth Nozzle. Gals. per Min.			⅞-Inch Smooth Nozzle, or 1-Inch Ring Nozzle. Gals. per Min.		
Lbs. per sq. in.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.
5	75	79	93	70	72	82	62	64	71	54	55	59	44	45	47
10	107	111	131	98	102	116	88	91	100	76	78	83	63	63	66
15	131	136	160	121	125	143	108	111	123	93	95	102	76	77	81
20	151	157	185	139	144	164	125	128	142	107	110	118	88	89	94
25	169	176	207	155	161	184	139	143	158	120	122	132	99	100	105
30	185	192	226	170	176	202	152	156	173	132	134	144	108	110	115
35	200	208	245	184	190	218	165	169	188	142	145	156	117	119	124
40	214	222	262	197	204	233	176	181	201	152	155	167	125	127	133
45	226	236	278	209	216	247	187	192	213	161	165	177	132	134	141
50	239	249	293	220	228	260	197	202	224	170	174	186	139	142	148
55	251	261	307	231	239	273	207	212	235	178	182	195	146	148	155
60	261	273	320	241	250	285	216	222	245	186	190	204	153	155	162
65	272	284	333	251	260	296	225	231	255	194	198	213	159	161	169
70	282	294	346	261	270	307	233	240	265	201	205	221	165	167	176
75	292	304	358	270	279	319	241	248	275	208	212	228	171	173	182
80	301	314	370	278	288	329	249	256	284	215	219	236	177	179	188
85	311	324	382	287	297	339	257	264	293	222	226	243	182	185	193
90	320	333	393	295	306	349	264	272	301	228	233	250	188	190	199
95	329	342	403	303	314	358	272	279	309	234	239	257	192	195	204
100	337	351	414	311	322	368	279	287	317	240	245	264	197	200	210

Quantities are stated in United States gallons of 231 cubic inches.

TABLES.

to 100 Feet of 2½-inch Hose.

TABLE B.—No. 2.
(From experiments of J. R. FREEMAN, 1888.)

¾-Inch Smooth Nozzle, or ¾-inch Ring Nozzle. Gals. per Min.			1⅜-Inch Ring Nozzle. Gals. per Min.			1¼-Inch Ring Nozzle. Gals. per Min.			1⅛-Inch Ring Nozzle. Gals. per Min.			HYDRANT PRESSURE.
Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose."—Inside Rough.	Ordinary best quality Rubber-lined Hose.—Inside Smooth.	Lbs. per sq. in.
34	34	35	67	69	78	60	62	68	52	53	57	5
48	49	50	94	97	110	85	87	96	74	75	81	10
59	60	61	115	120	135	104	107	117	90	92	99	15
68	69	71	133	138	155	120	123	135	105	107	114	20
76	77	79	149	154	174	134	138	151	117	119	128	25
84	84	87	163	169	191	147	151	165	128	130	140	30
90	91	93	176	182	206	159	163	179	139	141	151	35
97	97	100	188	195	219	169	174	191	148	151	162	40
103	103	106	200	207	233	180	185	203	157	160	172	45
108	109	112	211	218	245	190	195	214	165	169	181	50
113	114	117	221	229	257	199	204	224	173	177	189	55
118	119	122	231	239	269	208	213	234	181	185	198	60
123	124	127	241	248	280	217	222	244	189	192	206	65
128	129	132	250	258	291	225	230	253	195	199	213	70
132	133	137	259	267	301	233	239	262	203	206	221	75
137	138	142	267	275	311	240	246	270	209	213	228	80
141	142	146	275	284	320	247	254	279	215	219	235	85
145	146	150	283	292	329	255	261	287	222	226	242	90
149	150	154	291	300	338	262	269	295	228	232	249	95
153	154	158	299	308	347	269	275	302	234	238	255	100

NOTE.—The above figures for Ring Nozzle Discharges will apply to any ordinary form of Ring accurately enough for practical purposes, but apply especially to ordinary form of Ring Nozzle with square shoulder $\frac{1}{16}$ or $\frac{1}{8}$ inch deep.

Ring Nozzles with "under-cut" or "knife-edge" shoulder, discharge, as ordinarily constructed, about 3 per cent. less than quantity given above.

(If Gauge is not connected in this manner, proper allowance must be made for loss of pressure between Gauge and Hydrant.)

PUMP INSPECTION

The degree of accuracy attained in estimating of the two preceding tables — B, No. 1 and

HYDRANT PRESSURE indicated while Stream is flowing by Gauge attached to Hydrant, as shown.	Quantity of Water Discharged per minute through ordinary 2½-inch Fire Hose, (United States Gallons of 231 cubic inches.) Open Hose Butt. No Play.								
	Length 25 feet.			Length 50 feet.			Length 100 feet.		
Lbs. per sq. in.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose." Inside Rough.	Ordinary best quality Rubber-lined Hose. Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose." Inside Rough.	Ordinary best quality Rubber-lined Hose. Inside Smooth.	Unlined Linen Hose.	Inferior Rubber-lined Cotton "Mill Hose." Inside Rough.	Ordinary best quality Rubber-lined Hose. Inside Smooth
10	231	242	297	176	188	242	132	140	188
15	283	297	363	217	230	297	161	171	230
20	326	343	419	251	266	343	186	199	266
25	365	383	468	281	297	383	208	222	297
30	400	420	514	307	326	420	228	243	326
35	432	453	554	332	352	453	246	262	352
40	462	484	593	355	376	484	264	280	376
45	490	514	630	377	399	514	280	297	399
50	516	542	664	398	420	542	294	313	420
55	541	568	696	416	440	568	308	328	440
60	565	594	726	434	460	594	322	343	460
65	588	618	756	452	480	618	336	358	480
70	610	641	784	470	498	641	348	371	498
75	632	663	812	486	515	663	360	384	515
80	652	685	....	502	532	685	372	397	532
85	672	706	....	518	548	706	383	409	548
90	692	727	....	533	564	727	394	421	564
95	712	747	....	547	579	747	405	432	579
100	730	766	....	561	594	766	416	443	594
110	766	806	....	588	623	806	436	465	623
120	800	....	....	614	651	....	456	486	651

discharge would be 5 per cent. greater. / discharge would be 8 per cent. greater. / discharge would be 9 per cent. greater. / discharge would be 3 per cent. greater. / discharge would be 6 per cent. greater. / discharge would be 1½ per cent. greater. / discharge would be 2 per cent. greater. / discharge would be 4 per cent. greater. / discharge would be 6 per cent. greater. / discharge would be 8 per cent. greater. / discharge would be 10 per cent. greater. / discharge would be

TABLES.—"Open Butts."

TABLE B.—No. 3.

discharge through "Open Butt" is, not nearly so great as may be attained by the methods B, No. 2 — by reason of greater influence of form of Hydrant and differences in Hose.

with Couplings of 2½-inch Bore. Pipe or Nozzle attached.				Discharge through Open Butt of Hydrant, without Hose attached.	
Length 200 feet.		Length 400 feet.		HYDRANT PRESSURE indicated while Stream is flowing by Gauge attached to Hydrant, as shown.	Discharge of One Nipple of Chapman 4-Way Independent Gate Hydrant.
Inferior Rubber-lined Cotton "Mill Hose."	Ordinary best quality Rubber-lined Hose.	Inferior Rubber-lined Cotton "Mill Hose."	Ordinary best quality Rubber-lined Hose.	Diameter of Outlet exactly 2⅛ inches.	
Inside Rough.	Inside Smooth.	Inside Rough.	Inside Smooth.	Lbs. per sq. in.	Gals. per Min.
102	140	74	102	10	419
125	171	90	125	15	513
144	199	104	144	20	592
161	222	116	161	25	663
177	243	127	177	30	725
190	262	137	190	35	783
204	280	146	204	40	837
217	297	155	217	45	888
228	313	164	228	50	936
239	328	172	239	55	982
250	343	179	250	60	1026
260	358	186	260	65	1067
270	371	194	270	70	1108
279	384	201	279	75	1147
288	397	208	288	80	1184
297	409	215	297	85	1221
306	421	221	306	90	1256
314	432	227	314	95	1290
322	443	232	322	100	1326
338	465	243	338	110	....
354	486	254	354	120	....

NOTE.—Slight peculiarities of construction in different makes of Hydrants so affect discharge from open butts of Hydrants without Hose, that these figures apply only approximately to discharge of Hydrants in general.

By using good judgment in applying corrections as per notes below, results accurate to within 10 per cent. may generally be obtained.

(Style A.)—Ordinary Matthews (R. D. Wood & Co.'s) Hydrant without independent gates, inside corner being rounded off, will probably discharge about 20 per cent. more.

(Style B.)—Ordinary Chapman Hydrants without independent gates have square inside corners, and will probably discharge about 10 per cent. more.

For the ordinary Ludlow and Lowry Independent-Gate Hydrants or Chucks, figures in table are probably nearly correct.

If diameter of outlet is not exactly 2⅛ inches, an additional correction, as follows, must be made:—

Diameter.	Add.	Deduct.
2⅝	10 %	....
$2\frac{9}{16}$	5 %	....
$2\frac{7}{16}$	....	5 %
2⅜	....	10 %
2¼	....	19 %

TABLE C.

This is of much interest in illustrating what can be done with a given hydrant pressure, according to length and kind of hose used, and a study of this table shows up plainly facts which are far too little appreciated.

Note the difference in effective height and force of jet dependent on whether 500 or even 250 feet of hose is used, instead of 50 feet as is often used in practice tests by mill fire brigades.

Note, also, the inferiority of linen hose for use in long lines, such as are called for in connection with yard hydrants.

Thus, suppose that at a given mill there is available a static pressure of 80 pounds, and that the hydrant pipes are of such ample size that pressure at hydrant will be 70 pounds when streams are playing.

We see from table that if 1⅛-inch nozzles are used the height of the effective fire streams obtainable will be:

LENGTH OF HOSE.	GREATEST HEIGHT IN A MODERATE WIND AS A GOOD EFFECTIVE FIRE STREAM.	
	With ordinary 2½-inch unlined linen hose.	With smoothest 2½-inch rubber-lined hose.
Line 50 feet long	73 feet high.	81 feet high.
" 250 " "	42 "	61 "
" 500 " "	27 "	46 "

Note how quickly the inferiority of 2-inch hose develops when length much exceeds 50 or 100 feet.

Thus: with 250 feet of 2½-inch linen, effective height of stream = ... 42 feet.

With 250 feet of 2-inch linen, effective height of stream = ... 20 "

Note, also, the effect which even ⅛ inch increase in diameter has in reducing friction loss in the hose.

Thus, with 500 feet of smoothest and best rubber-lined hose—

If diameter be exactly 2½ inches, effective height of stream will be..... 39 feet.

If diameter be ⅛-inch larger, effective height of stream will be..... 46 "

PRESSURE in lbs. per sq. in. indicated at base of play-pipe,
HEIGHT, greatest, as good effective fire stream in moderate wind,
VOLUME in U. S. gallons per minute,

} of Jet obtainable with a given Hydrant Pressure, according to Size, Kind, and Length of Hose used.

TABLE C.

(From experiments of J. R. FREEMAN, 1888.)

TAKE NOTICE.—This "Given Hydrant Pressure" is pressure at the Hydrant, measured as shown in sketch, ***while stream is flowing.*** The Fire Pump Pressure (or Static Reservoir Pressure) must, meanwhile, be greater than this Hydrant Pressure by an amount equal to friction-loss between Pump and Hydrant. No general statement of the magnitude of this friction-loss can be made, as it depends on length and size of pipe-system, and number of streams being drawn, and may be anywhere from 5 to 40 or more pounds. In a thoroughly first-class Mill Hydrant System, this friction-loss through main pipes and valves ought not to generally exceed 10 or 15 lbs.

		1-Inch Smooth Nozzle.				1⅛-Inch Smooth Nozzle. This is size now generally preferred for outside use.								1¼-Inch Smooth Nozzle.			
Available Hydrant Pressure while Stream is Flowing—→		40	60	80	100	40	50	60	70	80	90	100	120	40	60	80	100
50 ft. Ordinary 2-in. Unlined Linen Hose. (Diam. couplings 2-in., but inside diam. hose 2¼-in.)	Noz. Pressure	**24**	**35**	**47**	**59**	**19**	**23**	**28**	**33**	**37**	**42**	**47**	**56**	**15**	**22**	**29**	**36**
	Height for Fire	42	58	71	78	34	41	49	56	61	67	72	81	28	41	52	61
	Galls. per Min.	144	174	202	226	164	180	199	216	229	244	258	282	181	219	252	282
50 ft. Ordinary 2½-in. Unlined Linen Hose. (Diam. couplings 2½-in., but inside diam. hose 2¾-in.)	Noz. Pressure	**31**	**47**	**63**	**78**	**28**	**35**	**41**	**48**	**55**	**62**	**69**	**83**	**24**	**36**	**47**	**59**
	Height for Fire	52	71	81	88	49	59	66	73	80	84	88	93	44	61	74	84
	Galls. per Min.	164	202	233	261	199	222	241	261	279	296	312	342	230	282	322	359
50 ft. Best 2½-in. Rubber-Lined Cotton Hose. Inside surface very smooth. (Diam. couplings 2½-in., inside diam. hose 2¾-in.)	Noz. Pressure	**35**	**52**	**70**	**87**	**32**	**40**	**48**	**56**	**64**	**73**	**81**	**97**	**29**	**44**	**58**	**73**
	Height for Fire	58	74	85	91	55	65	73	81	85	89	92	98	52	71	83	92
	Galls. per Min.	174	212	246	275	212	238	261	282	301	321	338	370	252	307	358	400
250 ft. Ordinary 2-in. Unlined Linen Hose. (Diam. couplings 2-in., but inside diam. hose 2¼-in.)	Noz. Pressure	**9**	**14**	**19**	**23**	**6**	**8**	**9**	**11**	**13**	**14**	**16**	**19**	**4**	**6**	**9**	**11**
	Height for Fire	17	24	33	40	13	15	17	20	23	25	29	34	9	13	17	21
	Galls. per Min.	90	110	128	141	102	106	16	126	140	147	150	164	97	120	139	155
250 ft. Ordinary 2½-in. Unlined Linen Hose. (Diam. couplings 2½-in., but inside diam. hose 2¾-in.)	Noz. Pressure	**18**	**28**	**37**	**46**	**14**	**17**	**21**	**24**	**27**	**31**	**34**	**41**	**10**	**15**	**20**	**25**
	Height for Fire	32	49	60	70	25	31	38	42	47	54	58	66	19	28	37	46
	Galls. per Min.	126	155	179	200	147	156	172	184	196	209	220	241	148	181	209	234
250 ft. Inferior 2½-in. Rubber-Lined "Mill Hose." Inside surface rough and uneven. (Inside diam. hose and coupling each exactly 2½-in.)	Noz. Pressure	**20**	**30**	**39**	**49**	**15**	**19**	**22**	**26**	**30**	**34**	**37**	**45**	**11**	**17**	**22**	**28**
	Height for Fire	35	51	63	72	27	34	39	46	52	58	61	70	21	32	41	50
	Galls. per Min.	132	161	184	206	146	164	177	192	206	220	229	252	155	192	219	247
250 ft. Best 2½-in. Rubber-Lined Cotton Hose. Inside surface very smooth. (Diam. couplings 2½-in., inside diam. hose 2¾-in.)	Noz. Pressure	**26**	**39**	**52**	**65**	**21**	**27**	**32**	**37**	**43**	**48**	**53**	**64**	**17**	**25**	**34**	**42**
	Height for Fire	45	63	74	82	38	47	55	61	68	73	78	85	32	46	59	69
	Galls. per Min.	150	184	212	237	172	196	212	229	247	261	274	301	192	234	273	304

500 ft. Ordinary 2½-in. Unlined Linen Hose. (Diam. coupling 2⅝-in., but inside diam. hose 2¾-in.)	Noz. Pressure	12	18	24	30	8	11	13	15	17	19	21	25	6	9	12	15
	Height for Fire	21	32	42	51	15	20	23	27	31	34	38	44	13	17	23	28
	Galls. per Min.	101	125	144	161	106	126	140	146	156	164	172	188	120	139	162	181
500 ft. Inferior 2½-in. Rubber-Lined "Mill Hose." Inside surface rough and uneven. (Inside diam. hose and coupling each exactly 2½-in.)	Noz. Pressure	13	20	27	33	9	12	14	16	19	21	23	28	7	10	13	17
	Height for Fire	23	35	46	55	17	22	25	29	34	38	41	49	13	19	24	32
	Galls. per Min.	106	132	153	169	116	130	147	150	164	172	180	199	120	148	169	192
500 ft. 2½-in. Rubber-Lined Cotton Hose. Inside surface very smooth. (Inside diam. hose and coupling each exactly 2½-in.)	Noz. Pressure	18	26	35	44	13	16	19	22	26	29	32	38	9	14	19	23
	Height for Fire	32	45	58	68	23	29	34	39	46	50	55	63	17	26	35	42
	Galls. per Min.	125	150	174	196	140	150	164	177	192	202	212	232	139	175	204	225
500 ft. Standard 2½-in. Rubber-Lined Cotton Hose. Inside surface very smooth. (Diam. coupling 2⅝-in., but inside diam. hose 2¾-in.)	Noz. Pressure	20	30	39	49	15	19	22	26	30	34	37	45	11	17	22	28
	Height for Fire	35	51	63	72	27	34	39	46	52	58	61	70	21	32	41	50
	Galls. per Min.	132	161	184	206	146	164	177	192	206	220	229	252	155	192	219	247
500 ft. 2¾-in. Rubber-Lined Cotton Hose. Inside surface very smooth. (Coupling 2⅞-in. bore, with taper. Inside diam. hose 2¾-in.)	Noz. Pressure	22	33	44	55	17	21	26	30	34	38	43	51	13	20	26	32
	Height for Fire	38	55	68	76	31	38	46	52	58	63	68	76	24	37	47	56
	Galls. per Min.	138	169	196	218	156	172	192	206	220	232	247	269	169	209	239	265
500 ft. 3-in. Rubber-Lined Cotton Hose. Inside surface very smooth. (Coupling 3⅛-in. bore, with taper. Inside diam. hose 3-in.)	Noz. Pressure	26	39	52	64	21	26	32	37	42	47	53	63	17	25	33	42
	Height for Fire	45	63	74	81	38	46	55	61	67	72	78	85	32	46	57	69
	Galls. per Min.	150	184	212	235	172	192	212	229	244	258	274	298	192	234	270	304
800 ft. Inferior 2½-in. Rubber-Lined "Mill Hose." Inside surface rough and uneven. (Inside diam. hose and coupling each exactly 2½-in.)	Noz. Pressure	10	14	19	24	7	8	10	11	13	15	16	19	5	7	9	11
	Height for Fire	18	24	33	42	12	15	18	20	23	27	29	34	9	13	17	21
	Galls. per Min.	93	110	128	144	96	106	119	126	140	146	150	164	105	123	139	155
800 ft. 2½-in. Rubber-Lined Cotton Hose. Inside surface very smooth. (Inside diam. hose and coupling each exactly 2½-in.)	Noz. Pressure	13	20	26	33	9	12	14	16	18	21	23	28	7	10	13	16
	Height for Fire	23	35	45	55	17	22	25	29	32	38	41	49	13	19	24	30
	Galls. per Min.	106	132	150	169	116	130	147	150	159	172	180	199	123	148	169	187
800 ft. Standard 2⅝-in. Rubber-Lined Cotton Hose. Inside surface very smooth. (Diam. coupling 2⅞-in., but inside diam. hose 2¾-in.)	Noz. Pressure	15	23	31	38	11	14	17	19	22	25	28	33	8	12	16	20
	Height for Fire	26	40	52	62	20	25	31	34	39	44	49	56	15	23	30	37
	Galls. per Min.	114	141	164	181	126	147	156	164	177	188	199	216	132	162	187	209
800 ft. 2¾-in. Rubber-Lined Cotton Hose. Inside surface very smooth. (Coupling 2⅞-in. bore, with taper. Inside diam. hose 2¾-in.)	Noz. Pressure	17	26	35	44	13	16	19	22	26	29	32	39	9	14	19	24
	Height for Fire	30	45	58	68	23	29	34	39	46	50	55	64	18	26	35	44
	Galls. per Min.	121	150	174	196	140	150	164	177	192	202	212	234	139	175	204	230
800 ft. 3-in. Rubber-Lined Cotton Hose. Inside surface very smooth. (Coupling 3⅛-in. bore, with taper. Inside diam. hose 3-in.)	Noz. Pressure	22	32	43	54	17	21	25	29	33	38	42	50	13	19	25	32
	Height for Fire	38	54	67	75	31	38	44	50	56	63	67	75	24	35	46	56
	Galls. per Min	138	166	193	216	156	172	188	202	216	232	244	266	169	204	234	266

Jet Diagram.

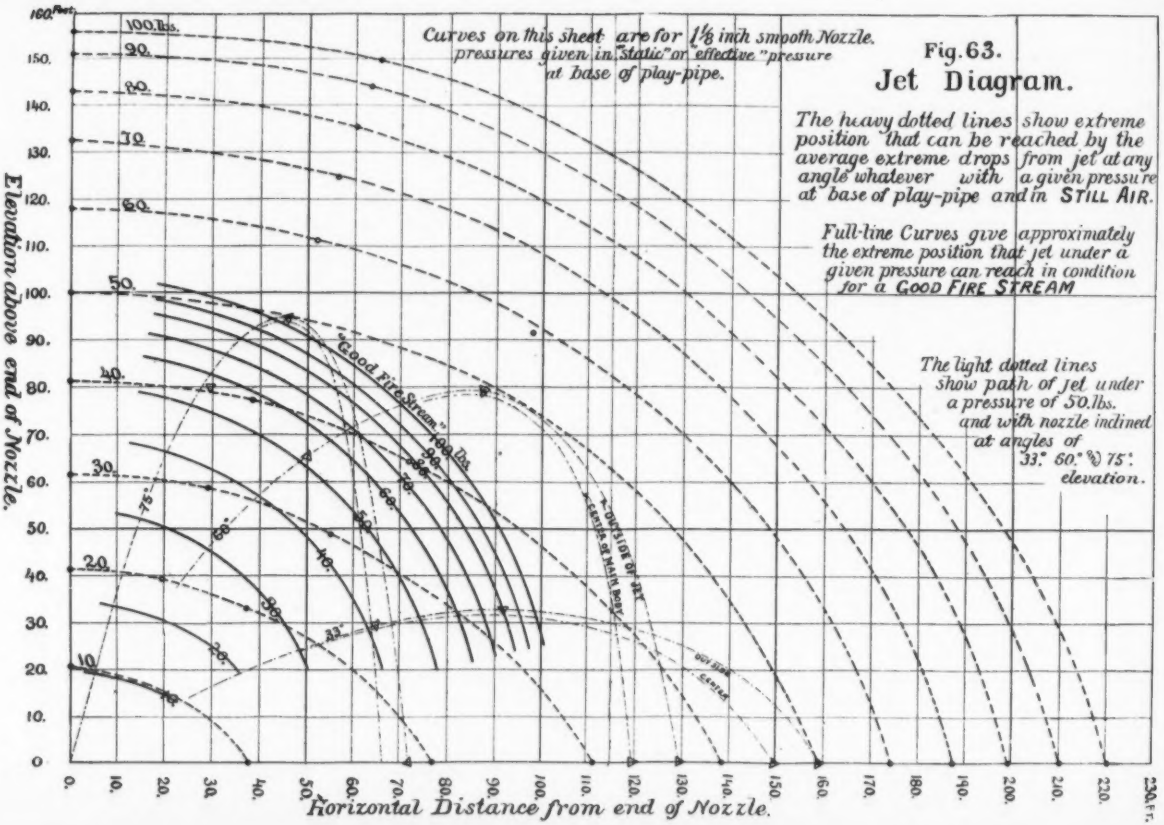
The diagram shown in Fig. 63 is constructed for convenient practical use in determining the reach of a jet under various pressures, and thus may be classed along with Tables A, B and C. It is of interest as illustrating what points of a structure are within reach of a jet of a given pressure from a given stand-point.

It is constructed solely from data in Tables 9, 10, 11 and 12, and in part by averages of these same data shown in Figs. 56 and 57. Had its construction been in view at the time of the experiments, more co-ordinates for the path of the jet would have been observed, and some experiments with 45 degrees inclination of nozzle would have been made for defining that portion of the curves with greater exactness, and some photographs of the exact path of the jet would also have been made.

The three curves for the path of a jet under 50 pounds pressure at angles of 75, 60 and 33 degrees, shown by the light dotted lines of Fig. 63, were not defined by such frequent co-ordinates as desirable; those actually determined are shown by the triangles, and between these points the curves were sketched in along what appeared the probable course.

It was thought they were of interest for comparison with the theoretical values for path of jets in which no allowance is made for resistance of the air, as given in various text books, and certainly they have greater practical value. The writer regrets he did not determine the path by photography, as could have been very accurately done, and presents these few curves for the path of jets merely until some other observer shall present more complete ones.

The curves for showing extreme distance at which stream can be classed as a good fire stream were drawn from the average results of the experiments recorded in Tables 9 to 12. The values recorded in the several experiments do not agree very closely; and, indeed, it is, in observing an ordinary fire stream, hard to say just exactly where it ceases to be good, within 5 or perhaps even 10 feet. On bringing together into this plotting the data from the several tables the results for the different elevations did not harmonize in some cases within 10 per cent. Perhaps on some days I was inclined to be a little more critical in defining extreme point of a good stream than on others. Thus we are now inclined to think that in defining limits as good and fair streams


Curves on this sheet are for 1⅛ inch smooth Nozzle.
pressures given in "Static" or effective "pressure at base of play-pipe.
Fig. 63.
Jet Diagram.
The heavy dotted lines show extreme position that can be reached by the average extreme drops from jet at any angle whatever with a given pressure at base of play-pipe and in STILL AIR.
Full-line Curves give approximately the extreme position that jet under a given pressure can reach in condition for a GOOD FIRE STREAM
The light dotted lines show path of jet under a pressure of 50 lbs. and with nozzle inclined at angles of 33° 60° & 75° elevation.
100 lbs.
90
80
70
60
50
40
30
20
10
"Good Fire Stream" 100 lbs.
OUTSIDE OF JET
CENTRE OF MASS Resp.
Elevation above end of Nozzle.
Horizontal Distance from end of Nozzle.
Feet.

in Table No. 12 the judgment was, perhaps, a little severe. After studying the various observations, it appeared to the writer that circular arcs, as shown in Fig. 63, would represent the values for the several angles of inclination of nozzle with no greater probable error than for a more complicated form. In other words, the necessary indefiniteness of the determination and the variations actually found in extreme distance to which a fire stream can for all circumstances be classed as "good" do not warrant giving a more complicated form to the curve. For pressures of 10 pounds and 20 pounds, the fact that water continues in a solid body more nearly to end of jet makes it necessary to deviate these two curves from circular arcs. The curves for limiting positions of extreme drops of jet are at most points probably about as nearly correct as the nature of the problem admits of determining with any ordinary means and appliances, and probably error does not exceed 2 or 3 per cent.; but possibly these curves at points lying between lines passing through origin of co-ordinates, and at angles of 20 and 40 degrees to horizontal axis, being in the gap between the observations, are drawn a little too flat; or, in other words, perhaps actually the drops might reach an additional 5 per cent. or so beyond the curve. However, it was thought best not to depart too widely from the line joining the experiments. The points determined by experiment in the several curves are shown by small circles on the plotting.

APPENDIX.

Formulas for Practical Use.

The following formulas deduced from well-known hydraulic laws, and based upon data from the experiments described in the foregoing paper, are inserted here for handy reference. They are useful for special cases or for dimensions not included in the practical tables presented above.

Case I.—To compute the discharge of a nozzle having given the pressure at its base.

Let d = diameter of orifice of discharge in inches.

D = diameter of channel past gauge connection in inches.

c = co-efficient of discharge of the particular kind of nozzle used. (For nozzles of ordinary forms we may assume $c = 0.974$ for smooth nozzles, and $c = 0.74$ for ring nozzles. See pages 316 to 332, and Figs. 8 to 26, as a guide to values of co-efficient for special shapes of smooth nozzles, and see page 334 as a guide to proper value of co-efficient for special shapes of ring nozzles.)

h_1 = head in feet indicated by gauge at base of play-pipe (first corrected, if necessary, for index error and for difference in level between gauge and orifice).

p_1 = pressure in pounds per square inch indicated by gauge at base of play-pipe (corrected for level, if necessary).

h = effective head or static head at base of play-pipe in feet.

p = effective pressure or static pressure at base of play-pipe in pounds.

$\triangle$ = diameter of hose.

The pressure at base of play-pipe or nozzle may be stated either as indicated pressure h_1 or effective pressure h.

The pressure h_1 indicated by the gauge is less than h, the static pressure or pressure effective in producing discharge and projection of jet, by an amount equal to the pressure theoretically due to the mean velocity of flow past the piezometer. If indicated pressure is given we can obtain the effective pressure by the following formula: $h = \frac{h_1}{1 - c^2 \left(\frac{d}{D}\right)^4}$.

If we have given the indicated pressure as represented in Fig. 64, the discharge in cubic feet per second = Q may be computed thus:—

$$Q = \frac{.04\ 374 \quad c\, d^2}{\sqrt{1 - c^2 \left(\frac{d}{D}\right)^4}} \sqrt{h_1} \qquad (1)$$

Or the discharge in gallons per minute = G.

$$G = \frac{29.83 \quad c\, d^2}{\sqrt{1 - c^2 \left(\frac{d}{D}\right)^4}} \sqrt{p_1} \qquad (2)$$

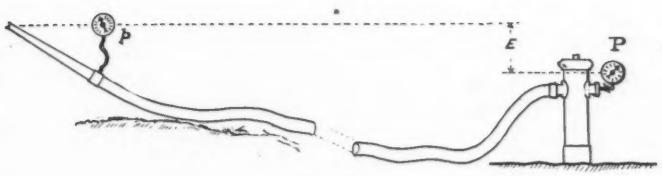


FIG. 64.

If we have the effective pressure $= h$ given, then

$$Q = .04\,374\, c\, d^2 \sqrt{h_1} \tag{3}$$

$$G = 29.83\, c\, d^2 \sqrt{p_1} \tag{4}$$

For approximate purposes, since h is ordinarily but little more than h_1, we may insert the indicated pressures in place of h and p in formulas Nos. 3 and 4.

To illustrate the error caused by this approximation, we may say that for the case of a 1⅛-inch smooth nozzle on 2½-inch hose, the computed discharge will be only 2 per cent. in error by its use.

For certain special cases other than fire stream nozzles, where D at base of nozzle is large, and gauge not perceptibly influenced by velocity of approach, the gauge reading (corrected for elevation and index error) will, without further correction, give h or p and thus permit formulas Nos. 3 or 4 to be accurately used.

Case II.—Given the hydrant pressure. Required the nozzle pressure:
Let P = pressure in top of hydrant in pounds per square inch.

(If orifice of nozzle is at an elevation higher or lower than hydrant gauge, then this gauge reading must first be reduced to the nozzle level by adding the pressure in pounds corresponding to difference of level if nozzle is lower than hydrant gauge, or subtracting this correction if nozzle is higher than gauge.)

Let c = co-efficient of discharge of nozzle, either ring or smooth.

o = co-efficient of discharge of hydrant nipple. For a sharp square-cornered entrance $o = 0.82$. For a perfect smooth round-cornered entrance $o = 1.0$. For ordinary hydrants this may be taken as 0.707, which was value found for a hydrant experimented upon.

d = diameter of orifice of nozzle in inches.

D = diameter of hydrant nipple in inches.

L = length of hose in feet.

F = the hose constant, for the particular size and kind of hose used.

p = static pressure at base of play pipe in pounds per square inch.

$$p = \frac{P}{c^2\, d^4 \left[\frac{1}{D^4}\left(\frac{1}{o^2}-1\right) + \frac{LF}{6472}\right] + 1.} \qquad (5)^*$$

This, being a general formula, is complicated.

Simpler formulas for special cases are given below.

The hose constant F is in fact the friction loss in pounds per 100 feet, with 240 gallons per minute flowing, for any given kind of hose, and depends for its value upon the diameter, roughness, obstructions and curves of the given line of hose.

In computing the foregoing practical tables, the following values of F were used:

For unlined linen hose.....$F = 30.$
Inferior rubber lined hose.....$F = 26.$
Smoothest rubber lined hose.....$F = 13.$

We can deduce the value of F for any given line of hose, as follows:

$$F = \frac{97.66}{\triangle^5}\, f + S + R \qquad (6)$$

In which f = friction loss in pounds per 100 feet for a flow of 240 gallons per minute in hose of exactly $2\frac{1}{2}$ inches diameter, and having the given quality of surface.

Experimental values of f for various given qualities of surface are given in Table No. 6, page 348, and the photographs of Fig. 47 may be referred to as showing with exactness the quality of surface to which these values apply.

---

* Formula No. 5 may be derived as follows (all heads being measured above horizontal datum plane passing through orifice of nozzle):

Let H = head in hydrant.
h = static head at base of play pipe.
h_1 = indicated head at base of play pipe.
h_2 = head due velocity in hydrant nipple.
h_3 = head lost by eddies due contraction in hydrant nipple.
h_4 = reduction of head at entrance, at hydrant nipple.
h_5 = head lost by friction in going whole length of hose.
V = mean velocity in hydrant nipple.
v = mean velocity in nozzle orifice.
c = co-efficient of discharge of nozzle.
o = co-efficient of discharge of hydrant nipple.

The total head is accounted for as follows:

$$H = h_4 + h_5 + h_1.$$

Diameter of up-stream and down-stream ends of hose may be assumed the same, and therefore $h_1 = h - h_2$. Also $h_4 = h_3 + h_2$.

Thus we may write $H = h_3 + h_5 + h$, we desire to express all these heads in terms of h. Evidently $h_3 = h_4 - h_2$, but since, by a general hydraulic law,

$$h_4 = \frac{h_2}{o} \therefore h_3 = h_2\left(\frac{1}{o^2}-1\right)$$

From these sources we transcribe the following values:

Sample A very smoothest solid rubber hose..... $f = 13.4$
" B ordinary solid rubber hose..... $f = 14.0$
" C very smoothest rubber lined fabric hose... $f = 14.1$
" K very rough rubber lined fabric hose..... $f = 25.5$
" J excellent leather hose..... $f = 21.5$
" L ordinary unlined linen or canvas hose..... $f = 33.3$

If the data for roughness of water way in any particular case happens to be most conveniently given in the shape of the constant commonly denoted by n in the well-known Chezy formula $v = n\,(r\,s)^{\frac{1}{2}}$, see page 358 (or sometimes denoted by c in the Kutter formula), we may, from the given value of n (or c), deduce f, since $f = \frac{204600.}{n^2}$

S, in formula No. 6, denotes the pounds pressure lost per 100 feet in length, due to sinuosity in course of hose, and with 240 gallons per minute flowing experiments on page 361 indicate that we may ordinarily call $S = 1$.

R, in formula No. 6, denotes the pounds pressure lost per 100 feet of hose, with 240 gallons per minute flowing, due to reductions of area or obstructions in the hose.

For the best hose this term R is zero, and may thus ordinarily be omitted, while for old style $2\frac{1}{4}$-inch-bore couplings on $2\frac{1}{2}$-inch hose, we see, from page 370, $R = 0.50$.

Obstructions, such as diaphragms or washers, may be allowed for as per values on page 372.

For all ordinary purposes we may

Assume $o = 0.707$ or the value actually found for co-efficient discharge of Chapman independent gate hydrant.
" $C = .974$ for ordinary smooth nozzles.
" $C = .74$ for ordinary ring nozzles.

Now, to find h_2 in terms of h:

$$\frac{h_2}{h} = \frac{V^2}{v^2}, \text{ but evidently } \frac{V}{v} = \frac{c\,d^2}{D^2} \therefore h_2 = \frac{c^2\,d^4}{D^4} \cdot h.$$

Therefore, $h_2 = \frac{c^2\,d^4}{D^4}\left(\frac{1}{o^2} - 1\right) h.$

Next, the friction in the hose being simply proportional to its length and to the square of the quantity flowing, and calling $p = 2.3095\,h$, we have

$$\frac{h_s}{2.3095\,F} = \frac{L}{100}\,\frac{G^2}{(240.)^2} \therefore h_s = \frac{L\,F\,G^2}{2494000.}$$

Substituting the value of G from Formula No. 1, we have $h_s = c^2\,d^4\,\frac{L\,F}{6472}\,h.$

Returning to our original equation, and substituting these values,

$$H = \frac{c^2\,d^4}{D}\left(\frac{1}{o^2} - 1\right) h + \frac{c^2\,d^4\,L\,F}{6472}\,h + h.$$

Whence $h = \dfrac{H}{c^2\,d^4\left[\frac{1}{D^4}\left(\frac{1}{o^2} - 1\right) + \frac{L\,F}{6472}\right] + 1.}$

And expressing pressures in pounds instead of feet-head, we get Formula No. 5.

Introducing these values we have the following formulas for obtaining (static) nozzle pressure when hydrant pressure is known:

For smooth nozzles $$p = \frac{P}{.949\ d^4\left(\frac{1}{D^4}+\frac{LF}{6472}\right)+1} \qquad (7)$$

For ring nozzles $$p = \frac{P}{.548\ d^4\left(\frac{1}{D^4}+\frac{LF}{6472}\right)+1} \qquad (8)$$

The following formula will serve for approximate purposes. The error involved in its use is small, consisting only of the assumption that O = co-efficient discharge hose nipple = 1.0, or a neglect to include the small waste of energy due to the contraction at entrance to hose. For lengths of hose greater than 200 feet, and nozzles not larger than 1¾ inch, this is so small relatively to loss within the hose itself, that the error due the use of the following formula will be of no practical importance.

For smooth nozzles $$p = \frac{P}{\frac{LFd^4}{6822}+1} \qquad (9)$$

For ring nozzles $$p = \frac{P}{\frac{LFd^4}{11819}+1} \qquad (10)$$

Having thus determined the effective pressure p at base of play-pipes, the discharge may be readily computed by formula No. 4. The extreme height to which a jet of the given size will rise in still air under this pressure is shown by diagram in Fig. 56, page 390.

The maximum height for practical use as a first-class fire stream, under adverse conditions as to wind, is shown by Fig. 56*b*.

The greatest horizontal distance that a stream of the given size and pressure can attain, is shown by the diagram Fig. 57, page 390. And the greatest horizontal distance as an effective fire stream, by Fig. 57*b*.

The jet diagram, Fig. 63, contains much information on these points condensed into very compact form; or if formulas are desired:

The extreme height to which a jet will rise under this pressure in still air may be found from the formulas given on pages 381 and 392, namely:

$$J = h - .00\ 135\ \frac{h^2}{d_1} \qquad (11)$$

In which J = height in feet to which average extreme drops of a vertical jet will rise in still air above level of nozzle.

d_1 = diameter of jet in inches. (For ring nozzles $d_1 = 0.86\ d$.)

h = static head in feet acting upon nozzle.

(Formula No. 10 gives pressure in pounds = p.
To reduce this to feet for use in No. 11, $h = 2.3095\ p$.)

Having determined J for extreme drops, the height attained by center of main body at top of jet will be about 90 per cent. of J for jets 100 feet high, or 94 per cent. of J for jets 75 feet high.

Height as a thoroughly first-class fire stream will be about

82 per cent. of J for jets where $J =$ 50 feet.
79 " " " 75 "
73 " " " 100 "
67 " " " 125 "
63 " " " 150 "

Discharge of Hose with Open Butts.

Required the hydrant pressure necessary to produce a given discharge. This is given by the following formula:

$$P = G^2 \left(\frac{0.001\ 123}{D^4\ o^2} + 0.000\ 000\ 1736\ L\ F \right) \tag{12}$$

The more common problem is: What will be the discharge under a given hydrant pressure. This is given by the formula:

$$G = \frac{\sqrt{P}}{\sqrt{\frac{0.001\ 123}{D^4\ o^2} + 0.000\ 000\ 1736\ L\ F}} \tag{13}$$

The above are general formulas for any diameter of hose and any degree of contraction at entrance to hydrant nipple.

For the special case of 2½-inch hose and a hydrant like the Chapman Valve Company's Independent Gate Hydrant, whose co-efficient discharge = .71, the equation becomes:

$$G = \frac{\sqrt{P}}{\sqrt{0.000\ 061 + 0.000\ 000\ 1736\ L\ F}} \tag{14}$$

In the above formulas—

G represents discharge in United States gallons per minute.
P represents pressure at hydrant in pounds per inch (measured as shown in Fig. 64).
D represents diameter of bore of hydrant nipple in inches.
o represents co-efficient of discharge of hydrant nipple.*
L represents length of hose in feet.
F represents friction loss for this particular size and kind of hose in pounds per 100 feet in length with 240 gallons flowing. (See pp. 458 and 459.)

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* For a sharp square-cornered entrance..... $o = 0.82$
For a perfectly smooth rounded entrance..... $o = 1.00$
For ordinary hydrants, to allow for disturbances, etc., the value found experimentally for the Chapman Hydrant had best be used, viz..... $o = .707$

DISCUSSION.

CLEMENS HERSCHEL, M. Am. Soc. C. E.—I think this paper is one distinctly advancing our knowledge of hydraulic facts. Witness the measurement and consequent result of different degrees of roughness on interior of pipes; the beautiful portrayal of the distribution of velocities in jets, skillfully measured, and as skillfully worked up in the results; the tests of different forms of nozzles; the discovery that a nozzle, taken in conjunction with the measurement of the pressure at its base, forms a ready and efficient metering apparatus for certain purposes.

MANSFIELD MERRIMAN, M. Am. Soc. C. E.—The numerous experiments detailed in this interesting and valuable paper deserve a more extended discussion than I am able to give, for a great deal of study could easily be devoted to the many new facts and conclusions which are presented. I think it was Galileo who said that it was easier for him to understand the laws governing the motion of the distant planets than the laws that control the flow of the water which is everywhere around us. This remark is as true to-day as it was two and a-half centuries ago. In hydraulics experiment rather than theory must be our guide, and if Mr. Freeman has by his careful observations weakened one or more theories previously held, his paper is all the more welcome.

That the tables of Ellis give the discharge from nozzles much too small has been apparent for some time, so that in my book on hydraulics I made no mention of his results, except that the co-efficient of discharge for smooth nozzles appeared to be about 30 per cent. greater than for ring nozzles. Mr. Freeman now shows that the mean coefficients are about 0.97 and 0.74. The results that he deduces concerning the precision of the smooth nozzle as an apparatus for measuring water seem to me to be a valuable addition to our hydraulic knowledge. I hope to see his suggestion regarding their use in pumping tests carried out, for it is probable that the common method of relying upon the piston displacement often gives the amount of water lifted as too large.

It must certainly be true, as the paper shows, that the form of the smooth nozzle has but a slight influence on the efficiency of the stream as compared with other elements. I was not, however, entirely prepared for the conclusion that the conical nozzle is superior to all others in this slight influence. The "uniform acceleration nozzle," used in the experiments, had its tip straight for one inch in length, and although this probably exercised but a slight difference upon the result, yet it would have been as well to have made the entire profile in strict accordance with the equation of the curve. In this connection it may be noted

that the definition of uniform acceleration given on page 403 is incorrect. Uniform acceleration does not imply that a force is instantly applied and then instantly removed, but that the force acts constantly and with uniform intensity in exactly the same manner as the force of gravity. Hence it might be supposed, if the particles of water in their passage from the play-pipe to the tip of the nozzle are subject to the same uniform force or impulse, that there would be less loss of head due to eddies and cross-currents than when the form allows a variation in this force. It is indeed only for this reason, as I take it, that the form called the "uniform acceleration nozzle" has been supposed likely to give a higher co-efficient of discharge than other kinds.

The piezometer couplings used by Mr. Freeman are designed in accordance with what I believe to be sound hydraulic theory, and are more likely to register the mean static pressure of the water flowing through them than any other form I can imagine. Piezometric measurements have been so often subject to errors due to imperfect kinds of connection that it is to be hoped that this method may become a standard for measurements of flow in pipes as well as in hose.

The formula given by Weisbach for the co-efficient of discharge in cases of imperfect contraction seems unnecessarily complex in form if the true law of variation can be represented by a hyperbola, as the experiments plotted in Fig. 46 of the paper seem to indicate. Assuming 0.61 as the mean co-efficient for perfect contraction, and 1.00 for the case of no contraction, I find for the co-efficient of discharge for imperfect contractions, the formula,

$$c = 0.571 + \frac{0.0429}{1.1 - r}$$

in which r is the ratio of the diameter of the orifice to the diameter of the channel of approach. The degree of agreement between the actual co efficients found by Mr. Freeman for square ring nozzles and those computed from this formula is shown by the following comparison:

For	$r =$	0.500	0.833	0.848	0.886	0.950	1.000
By experiment,	$c =$	0.634	0.736	0.729	0.742	0.866	0.975
By formula,	$c =$	0.643	0.732	0.741	0.771	0.857	1.000
Per cent. difference,		+1.4	−0.6	+1.6	+3.9	−1.0	+2.6

The ingenious method used by Mr. Freeman for determining the distribution of velocities throughout the cross-section of jets deserves especial notice, for it is certainly a matter of much surprise and congratulation that the instrument known as Pitot's tube can be so modified as to be used for this purpose with such satisfactory results. The only criticism I have to offer is that its co-efficient may probably be subject to some variation with the velocity, particularly for such a minute orifice, whereas in the discussion of the experiments it was regarded as the same for all points in the same cross-section. If the

curve for the jet from the 1½ inch pipe, shown in Fig. 61, represents the variation of velocities within the pipe as well as in the stream after leaving it, it is no wonder that formulas for flow based upon the mean velocity have proved unsatisfactory. Probably, however, the relative variation is much less marked for the usual velocities of flow than for the high velocities that were used in the experiments.

Mr. FREEMAN.—Professor Merriman states that the definition of uniform acceleration on page 403 is incorrect. This was a special definition intended to bring out forcibly the fact that with the so-called uniform acceleration nozzle the whole available accelerating force was instantly applied in its full magnitude instead of being applied first gently and then with gradually increasing intensity, thus producing an acceleration which gradually increases up to the instant of discharge, as is the case with a plain conical nozzle.

I still hold to the correctness of the original statement. If a force acts only with a uniform intensity, then it, of course, does not act with varying intensity, and thus, not gradually increasing, is applied instantly at its full intensity, just as is the force of gravity when one cuts the string suspending a body.

We desired to call attention to this from the fact that there seems to be a sort of popular misapprehension on this very point, and hence a notion that the uniform acceleration nozzle would have special virtues. I shared these notions myself once, but on considering the matter in the light above stated, saw this notion was without reason or analogy. For, to state the case in a popular and not strictly scientific manner, if it were desired to get a train of cars from a state of rest or a slow velocity up to a very high velocity with the least possible shock, the engine driver should open his throttle gradually and not give it full force of steam at a jump. This analogy, of course, is of itself no demonstration of the superiority of a conical nozzle. In fact, as I said in the body of the paper, I consider the question to be one, first, of so shaping the nozzle that there shall be no tendency to form cross-currents or eddies; and, second, of keeping the channel large and the velocity and friction loss consequently low, up to as near the point of discharge as is practicable.

A very fair question is suggested in Professor Merriman's discussion as to whether the co-efficient of the modification of Pitot's tube used in determining the distribution of volocities may not have varied with the different velocities found in different points in the cross section. I am very glad this point is brought up, as it reminds me to say that I took care to investigate this question by experimenting upon the distribution of velocity in other jets from some of the same nozzles at much lower pressures, and found the ratio of the central velocity to the theoretical velocity due the head, and also the proportional distribution of

velocity to be substantially the same as for the very high velocity shown in Fig. 62. As to his further question implied as to whether the distribution of velocity in the jet from pipes of uniform diameter shown in Fig. 61 is the same as exists within the pipe itself, it seems to me there can be little doubt that this is the case, for the velocity of the particles of water was measured in less than a thousandth part of a second after they had left the tube, and their inertia must have continued them for this length of time at about the same rate of speed as before they left the tube.

It may be of interest to note the approximately parabolic form of this curve.

E. KUICHLING, M. Am. Soc. C. E.—The description and record of the experiments made by Mr. Freeman constitute an important and valuable contribution to the subject of practical hydraulics; and as the array of facts presented is exceedingly numerous and relates to a variety of distinct investigations, a long period of time would be required to give to each one of these investigations the careful study which legitimate criticism involves. In the absence of opportunity to devote more than a few hours at the present time to a review of the paper, the following remarks, relating only to the subject of the loss of pressure by friction in rubber fire hose, are offered.

To many persons the knowledge of the physical laws which govern the results of a series of experiments is of far more interest than the long array of figures and tables necessarily attendant upon all investigations of the character under consideration. These laws, when expressed in the condensed form of a general equation, are generally far more convenient for an engineer's ordinary use than a long table, which occupies much room in a note-book and requires a long time to copy. By means of the equations, moreover, valuable comparisons with other similar expressions can be instituted with ease and brevity, thereby facilitating the discovery of errors on the one or the other side. To illustrate this point it may be said that the law governing the loss of pressure by the friction of the water in its passage through fire hose can approximately be expressed by an equation of the following general form:

$$p = a\,Q^2; \quad \text{or} \quad Q = b\sqrt{p}. \tag{1}$$ (2)

where (p) denotes the loss of pressure in pounds per square inch by friction in every length of 100 feet of fire-hose; (Q) denotes the discharge through such hose in gallons per minute, and (a and b) certain empirical constants deduced from the results of the experiments, and dependent upon the diameter and quality of the hose used. In the foregoing expression $b = \sqrt{\frac{1}{a}}$, and the other elements are taken for convenience in the same terms given in the tables. The above formulas express that the friction loss in pressure varies with the square of the

discharge, or that the discharge varies with the square root of the friction loss in pressure, the exact numerical values depending upon the value of (a) found by trial. In this compact form, the results of a vast amount of labor performed by the author can be made practically available.

To find whether the experimental results obtained by the author in the above-named subject are in accordance with the general law just enunciated, we may deduce the value of the co-efficient (a) or (b) by substituting the measured values of (p) and (Q) in the expressions $a = \frac{p}{Q^2}$ or, $b = \frac{Q}{\sqrt{p}}$; and if the deduced value is substantially the same in every instance, it may be concluded that the said law has been established. Taking the case of experiments No. 21 to 31 inclusive, contained in Table No. 5, page 342, which were made with Sample K of 2½-inch woven cotton, rubber-lined mill hose, having an average internal diameter of 2.53 inches with an average water-pressure of 49 pounds per square inch, we will obtain the following results:

TABLE A.

1	2	3	4	5	6
No. of Experiment.	Loss of Pressure per 100 feet of hose. (p) pounds.	Discharge in gallons per minute (Q).	Deduced value of co-efficient (a).	Computed value of (Q) with $a = 0.0004239$.	Computed value of (Q) by Formula 8.
21	1.12	54.4	0.00037846	51.40	48.81
22	2.63	81.0	0.00040083	78.77	80.18
23	5.07	108.7	0.00042909	109.36	
24	6.83	125.4	0.00043433	126.93	132.03
25	6.91	126.8	0.00042977	127.68	132.79
26	11.03	159.1	0.00043575	161.31	
27	14.87	186.3	0.00042843	187.29	
28	18.93	211.3	0.00042399	211.32	215.60
29	22.29	229.8	0.00042210	229.31	232.52
30	24.88	243.6	0.00041927	242.27	244.53
31	28.06	259.9	0.00041541	257.28	258.34
	Average of entire 11 values=		0.00041977		
	Average of last 10 values=		0.00042390		

An examination of these values of (a) in the fourth column of the foregoing table shows a striking uniformity in every instance except the first; and if we consider the latter as being affected by some error of observation, the average of the ten following values of (a) gives: $a = 0.000\,4239$, whence $b = 48.570$. The results of this series of experiments may therefore be expressed by the formulas:

(3) $$p = 0.0004239\ Q^2, \quad \text{or} \quad Q = 48.57\ \sqrt{p},$$ (4)

from the latter of which the values of (Q) contained in the fifth column of the table were computed, for the sake of comparison, with the actually observed values contained in the third column. The agreement between these values of (Q) is so close that we may now regard the law above stated as fairly well demonstrated, and that for the particular kind of fire-hose represented by sample K, the loss of pressure due to friction may accurately be calculated from equation 3.

It may also be of interest to compare the above results with those obtained in 1877 at Springfield, Mass., by Mr. George A. Ellis, C. E., to which the author has referred. The details of these latter experiments are by no means as completely given as in the case of Mr. Freeman's work, and the record of the essential experiments on the loss of pressure in hose, as printed in Table No. 6, page 47, of Mr. Ellis' little manual, gives some evidence of more of less interpolation and modification of the actual observations. However, taking out a number of the data therein given, and following the same course pursued above, we obtain for the 2½-inch rubber hose specified:

TABLE B.

1	2	3	4	5	6
No. of Experiment.	Loss of pressure per 100 feet of hose, (p) pounds.	Discharge in gallons per minute (Q).	Deduced value of co-efficient (a).	Computed value of (Q) with $a = 0.00036414$.	Computed value of (Q) by Formula 7.
1	1.40	50.0	0.00056000	62.01	55.98
2	2.51	80.0	0.00039219	83.02	80.05
3	4.34	110.0	0.00035868	109.17	109.02
4	7.90	150.0	0.00035111	147.29	149.57
5	14.15	200.0	0.00035375	197.13	200.17
6	22.40	250.0	0.00035840	248.02	249.58
7	32.65	300.0	0.00036278	299.44	297 61
8	44.90	350.0	0.00036653	351.15	344.31
9	59.15	400.0	0.00036969	403.04	389.81
		Average of last 8 values = 0.00036414			

By rejecting the first of these data, we obtain an average value for the co-efficient, $a = 0.00036414$, whence $b = 52.404$, so that according to Ellis' figures we should have for said fire-hose:

$$p = 0.00036414\ Q^2; \quad \text{or} \quad Q = 52.404\ \sqrt{p}. \tag{6}$$

It will accordingly be seen that for the same discharge (Q), the loss of pressure by friction in pounds per square inch per 100 feet length of hose will be 1.079 times greater by Mr. Freeman's figures than by Mr. Ellis' data, or for the same loss of pressure (p), the discharge will be 1.164 times greater by Mr. Ellis' figures than by Mr. Freeman's.

An attempt was also made to find a formula which would represent

the law governing the loss of pressure by friction in such hose somewhat more accurately than by the expression $Q = b\sqrt{p}$, especially within the range of discharges usually observed in practice. In the case of Mr. Ellis' data, the writer found that the formula

$$Q = 191.88\sqrt[4]{p}\,(1.2332\sqrt[12]{p} - 1) \qquad (7)$$

would give the results exhibited in column 6 of Table B, which agree much more closely with the alleged actual observations in the third column of said table, between the limits $Q = 80$ and $Q = 250$, than the computations obtained from equation 6. A similar process of deduction applied to Mr. Freeman's data in Table A gives

$$Q = 162.98\sqrt[4]{p}\,(1.279\sqrt[12]{p} - 1) \qquad (8)$$

which yields the values contained in the sixth column of said Table A. The agreement between these values and the recorded observations is not as good as when equation 4 is used, and hence we may infer that equation 8 fails to express properly the law governing the loss of pressure due to friction. This inference is further warranted by the failure of a formula similar to equations 7 and 8, to agree with the results of experiments with iron pipes, and the form of expression is alluded to here simply because it fits the Ellis tables much closer than any of the others which the writer tried to apply in the course of a long examination of said data; but as Mr. Freeman's careful experiments now clearly point out that the law relating to the flow of water through fire-hose is the same as that pertaining to flow in other pipes, there is no occasion to resort to such complex formulas as those last mentioned.

With reference to the height of jets, it may be of interest to mention briefly the following few observations made with unusually large vertical streams during the official trial of the pumping machinery of the Rochester, N. Y., Water-works, on February 18th, 1874:

Diameter of orifice of ring nozzle.	Pressure in 16-in main at base of nozzle. Pounds per square inch.	Discharge in gallons per minute.	Vertical height of Jet in feet above street surface.	Remarks.
2 inches.	160	1 215	210.34	Three lines of 2½-inch fire hose from two hydrants to Siamese coupling and play-pipe.
3 "	170	2 778	285.98	Height measured by vertical angles from three different stations with different instruments and observers. Figures are averages.
4 "	165	4 938	294.40	Do. do.
5 "	120	6 463	256.80	Do. do.

The pressures in the second column of the foregoing Table are the averages of frequent observations on a Bourdon gauge, while each experiment was in progress, the gauge being located directly on the street main, and at one end of the 16 × 10-inch branch to which the vertical play-pipe was attached. According to the writer's recollection, the variation of the pressure gauge during the trials was comparatively slight, not exceeding a very few pounds. The discharge was estimated from the number of strokes made per minute by the pumps, as determined by counters, and probably contains only a small allowance, if any, for slip. The play-pipe for the 3, 4 and 5-inch streams was about 7 feet in length, and that for the 2-inch stream was about 5 feet long. All of the nozzles were provided with rings at the mouth. The observed heights refer to the extreme jets of solid water, as the spray was almost invisible through the telescopes. A 4-inch stream was also thrown, under an inclination of about 40 degrees from the horizon, to a distance of 465 feet, measured along the level street. It is greatly regretted that more precautions to insure a higher degree of accuracy for the above data were not taken at the time, and therefore they can only be regarded as approximations so far as pressure and discharge are concerned. For this reason, also, no attempt was made by the writer to compare the observed heights with the results obtained from the various formulas then available.

There is evidently a vast amount of exceedingly valuable material in Mr. Freeman's paper, and it is earnestly hoped that he may be induced to supplement his present work by a digest of the various analyses and mathematical investigations to which he has called attention.

I am highly pleased with the elegant exposure of the fallacy of the superiority of the ring nozzle and the undercut nozzle, as I have never been able to see, either from theory or practice, wherein their alleged superiority lies, yet nearly every mechanic and fireman whom I have met in this country insists that the ring or the undercutting is a vast improvement over the smooth bore. The question of size of hose is also of immense importance and significance, and I rejoice to see another champion enter the lists to battle for 3-inch hose, whose use in communities where the buildings are, with few exceptions, highly inflammable, and where the water pressure available is light, would be sure to effect a great reduction in the annual losses by fire.

Mr. FREEMAN.—The fact brought out by Mr. Kuichling's Table A, that the friction loss varies almost exactly as the square of the velocity is illustrated in what seems to me a more clear and striking manner by the plottings of Fig. 48, where the full lines are the curves of observations, and the dotted lines, which coincide so closely with them, are mathematical curves of squares.

Referring to the equation with twelfth roots, which Mr. Kuichling

so ingeniously devised to fit the Ellis Experiments, I fully coincide with the view implied by Mr. Kuichling, that the complex form was not due to any hydraulic law so much as to attempting to provide an equation which should fit errors of observation.

As to the experiments on Jets, presented by Mr. Kuichling, with the statements that he regarded them only as somewhat roughly approximate, I have thought it worth while to compare them with the jet formula of page 392 (using $d_1 = 2$ for jets more than 2 inches in diameter) and obtain the following results:

Diameter of orifice of Ring Nozzle. Inches.	Gallons per minute discharged, allowing 5 per cent for slip.	Observed head at water main. Pounds.	Co-efficient of discharge. Supposing full observed head utilized in producing discharge.	Actual diameter of Jet. d_2.	Height of Jet by formula. Feet.	Observed height. Feet.	Error. Feet.
2	1 154	160	.76	1.74	263	210	− 53
3	2 639	170	.75	2.61	289	286	− 3
4	4 692	165	.77	2.48	283	294	+ 11
5	6 140	120	.75	4.35	225	257	+ 22

In the first experiment, though description is vague, probably the discrepancy is mainly due to friction loss in the three lines of hose leading to Siamese. In the last three experiments the fact that height of solid water rather than extreme drops was observed tends to offset friction loss between gauge and nozzle, but with such large jets the extreme drops do not rise much higher than the main body of water.

The co efficient of discharge found (0.76) is about what would be expected from a ring nozzle where the ring was of an ordinary thickness, namely, one-twentieth part of diameter of nozzle (see Fig. 46, page 335). However, since co-efficient of contraction, force of wind, loss of pressure by friction between gauge and nozzle, and elevation of gauge relatively to orifice are not known, we must, as Mr. Kuichling implies, not attach too much weight to these experiments, but can regard them, I think, as confirming, and in no wise contradicting, the formula presented in the paper.

G. F. SWAIN, Assoc. Am. Soc. C. E.—The paper by Mr. Freeman seems to me to be a very important contribution to the science of hydraulics, particularly as it discusses with great completeness a branch of the subject regarding which experimental data have hitherto been very meagre.

I have been particularly struck with the care that has been taken to state clearly in every case the probable limits of error of the observations. I think this is a matter deserving of imitation, as it is not uncommon for experimenters to deceive themselves as well as their readers by attributing to the results of experiments an accuracy not warranted by the experiments themselves.

The experiments on the discharge of nozzles are very interesting to me, as showing that the co-efficient of discharge and range of jet are practically independent of the particular shape of the surface, but that they will be nearly the same for any smooth, well-made nozzle, either conical or with any curved shape in which the curve is gradual and easy, and such as to avoid as far as possible any losses of head; thus confirming the experimental results which have been found in the testing of turbine wheels, in which the precise shape of the buckets is found to be practically of small importance, as is observed by Mr. Freeman. With a given head at base of play-pipe, the only thing that can affect the co-efficient of discharge is the loss of head between the piezometer and the nozzle orifice, and it is not at once evident just how any difference in the form of the curve will affect this loss. As the author gives no formulas, it may not be out of place to give here the expression for the loss of head between the piezometer and the nozzle orifice, in terms of the co-efficient of discharge.

If v is the mean velocity through the nozzle orifice, v_0 that past the piezometer orifices, A and A_0 the areas of the current at these two points, Θ the loss of head between these points, m the co-efficient of discharge, and h the head of the piezometer, above the level of the nozzle orifice, then we have, as is well known,

$$v = \sqrt{\frac{2g\ (h-\Theta)}{1-\left(\frac{A}{A_0}\right)^2}}$$

The actual discharge is, therefore,

$$Q = Av = A\sqrt{\frac{2g\ (h-\Theta)}{1-\left(\frac{A}{A_0}\right)^2}}$$

What is termed the "theoretical discharge," or that in which Θ is neglected is,

$$Q_1 = A\sqrt{\frac{2\,gh}{1-\left(\frac{A}{A_0}\right)^2}}$$

$$\text{Hence} \quad m = \frac{Q}{Q_1} = \sqrt{1 - \frac{\Theta}{h}}$$

$$\text{or} \quad \Theta = h\,(1 - m^2)$$

Theoretically, therefore, the value of m should vary with the same nozzle unless $\frac{\Theta}{h}$ is constant. It might be of some interest to discuss from these observations the relations between m, Θ and h, for the different nozzles used, but it will not be here attempted. It may be noticed, however, that the data on pages 328 and 329 show that for the nozzle B, for instance (as well as for others), the loss of head Θ is less than for any of the "uniform accelleration" nozzles, since for B the value of m is greater, even for the same or for smaller values of h.

The result arrived at by Mr. Freeman, that extreme accuracy may be obtained in the measurement of water by means of nozzles, strikes me as of great practical importance, and one that should bear rich fruit. If the accuracy obtained by the use of a nozzle is as great as that which can be obtained by the use of a weir, there can be no question that the former method is in very many cases preferable, and it certainly seems, as Mr. Freeman says, to offer an easy means of testing, as often as may be desired, and with very little trouble, the performance of a pumping engine. It is to be hoped that Mr. Freeman may be able to suggest convenient means by which this method of measurement may be easily and accurately used in the case of pumping engines of large capacity.

The experiments of Mr. Freeman upon flow of water through fire hose are of much interest to me, and the ingenious expedient of taking a plaster cast of the interior of the hose is the first attempt that I can now recall to give a precise idea of the degree of roughness in a pipe. It is a matter of some speculative interest, how far it is the degree of roughness alone which affects the flow of water in pipes, and how far, if at all, it is anything in the nature of the material itself, which may affect the flow by influencing the adhesion, or in some other way.

The result of the experiments on curves, namely, that the loss of head was greater with large than with small radii, is anomalous, and a larger number of experiments than were here made would be necessary to establish it conclusively. A careful study of these experiments, which I have not yet had time to make, might indeed suggest some explanation of the anomaly.

The experiments on jets appear to me to be without doubt the best that have ever been made, in this or any other country; and an especially valuable point, it seems to me, is that the distinction is here made, for the first time, between the range of the extreme drops, and the range as a "good fire stream," uncertain though the latter is. The "jet diagram" (Fig. 63) is a very compact and ingenious means of rep-

resenting the results of the experiments, and it is only to be regretted that more data were not obtained, in order that the curves shown might be more accurately defined. As it is, many of them appear to rest on three observations simply. The experiments on the distribution of velocity in jets are of great interest, and the agreement between the theoretical velocity and the measured velocity in the center of the jet appears very close. I may venture, however, to call attention to the fact that there are two circumstances which may alter, perhaps materially, the figures in the column of differences on page 414. One is that in correcting for velocity past piezometer the actual discharge has been used instead of the theoretical, as should strictly be the case; the "theoretical velocity" being thereby decreased, although by a very small amount—an amount, however, which would probably be material compared with the small values in the column of differences. The other is that the co-efficient of the Pitot tube has been assumed as unity, whereas it has commonly been supposed to be somewhat less. There does not appear to be any theoretical reason, however, why there should be any perceptible or considerable loss of head in the center of the jet, within the distance considered, at least with a form of nozzle which would not cause internal disturbances, or throw toward the center the slower-moving water near the edges of the tube; and these experiments (especially the extraordinarily close agreement between the measured and computed co-efficients of discharge, on page 418) may be looked upon, as Mr. Freeman says, as proving very satisfactorily that the co-efficient of the instrument was unity, or very near it. The table on page 414 shows a greater difference between the theoretical velocity and actual velocity in center of jet in the case of the uniform acceleration nozzle than for any other, thus indicating a greater loss of head, and corresponding to the result on page 472 of this discussion. This may perhaps be due to the fact that the shape of the nozzle is such as to tend to throw toward the center the more slowly-moving water near the periphery. The same thing might be considered to be indicated by the form of the curve of distribution of velocity for this nozzle.

Altogether, I think it would be difficult to overrate the importance and interest of the experiments described in this paper.

MR. FREEMAN.—With reference to the point raised by Professor Swain that a larger number of experiments is needed to establish that the loss of head due curves of a given total angle of curvature was greater for large radii than for small, I would say that I think there is almost no doubt whatever but that this was a fact within the limits of these experiments; but yet, of course, I believe that as radius of curve became smaller than ten times diameter of pipe, a point would soon be reached when loss would increase sharply with a further diminution of radius of curve. The inexpansible and excellent hose used was much

better than any metallic pipe for the purpose of this delicate measurement, as the surface for the different radii was identical and the change from one radius to another was made with water flowing under full pressure, and required but a very short time.

When I at first obtained the results referred to I could not credit them myself, so about two weeks later I rearranged my apparatus, taking all precautions that could be devised to reduce errors of observation to a minimum. These experiments (see page 363, September 24th) told the same story as before; and though, after considering the possible limits of error at every step, I could see no reason to doubt the figures, yet in the effort to remove all doubts I tried another set of experiments on the next day with still a different kind of hose, and for the third time found that the loss in this 2½-inch pipe was greater with 4 feet radius than with 3 feet, and greater with 3 feet radius than with 2 feet. The loss even for the 2-foot radius is extremely small even with the velocity of 20 feet per second, and this experiment is mainly of theoretical interest in illustrating that above a certain radius the length of a curve becomes a more potent element than the sharpness of the deflection.

I am glad Professor Swain called attention to that question of speculative interest—how far it is the degree of roughness alone which affects the flow, and how far the material of the pipe by its adhesion, etc.—for it seems to me these experiments indicate that it is almost wholly a matter of the roughness of the material.

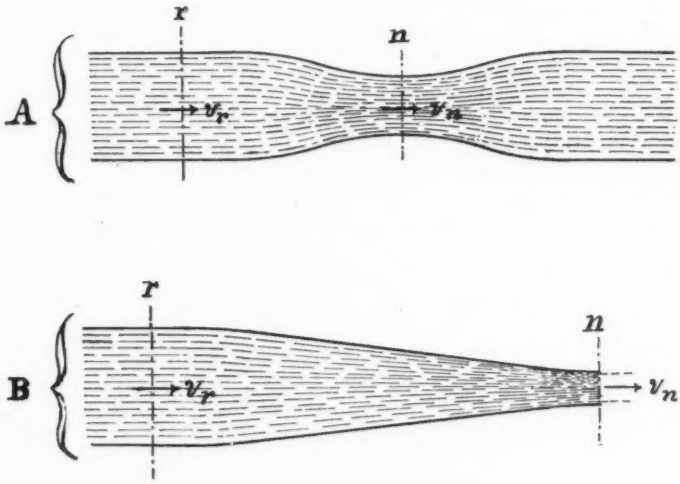
The experiments show a great range of co-efficients of flow with one material—India rubber—in various degrees of roughness, and the smoothest of these surfaces gives results which, as I now recall the comparison, do not differ very materially from those found with pipes of glass and lead, so far as may be judged from the few experiments on record for anywhere near this same diameter and velocity. If there were on record some experiments on pipes of lead and glass of 2½-inch diameter, with velocities of about 15 feet per second, there would be great interest in comparing the results.

Professor I. P. CHURCH.—It is with considerable diffidence that I venture to send anything in the way of criticism on the Fire Stream paper, from the necessary haste with which I have looked it over. I could not fail to be impressed, however, with the care and thoroughness observed in the conducting of the experiments, and the pains taken to make a definite showing of the degree of roughness of the interior surface of the hose. The Pitot tube results are extremely interesting, and I hope may be succeeded by others in which the form and size of the point receiving the impact will be varied in different ways. Taken all in all, this series of experiments certainly constitutes a very important contribution to

hydraulic science, to say nothing of its practical value to those interested in the actual use of fire streams.

A theoretical point occurs to me, as it did also in perusing the results of Mr. Herschel's paper on the Venturi water-meter,* connected with the computation of the theoretical jet velocity due to pressure at base of play-pipe. It may seem hypercritical to mention it, as its influence on Mr. Freeman's co-efficients for nozzles would be hardly appreciable, but, if I remember rightly, some of the values in one of Mr. Herschel's columns would be sensibly affected.

In the following figures let p and p_n be the observed piezometer pressures at the positions r and n, γ the weight of a unit of volume of water, and b the height of the water barometer. A represents a longitudinal section of the Venturi meter and B that of a play-pipe and nozzle. Of course in B the piezometer pressure at n is zero.



v_r and v_n denoting the velocities at the two positions (at the same level), the principle of Bernoulli tells us that with no source of resistance between r and n we have

$$\frac{p_r}{\gamma}+b+\frac{v_r^2}{2g}=\frac{p_n}{\gamma}+b+\frac{v_n^2}{2g} \text{ for } A\text{; and } \frac{p_r}{\gamma}+b+\frac{v_r^2}{2g}=0+b+\frac{v_n^2}{2g} \text{ for } B \quad (1)$$

* Transactions, Vol. XVII, p. 228, November, 1887.

It is required to compute the theoretical value (*i. e.*, the value if there were no loss of head between r and n) of v_n, from the observed pressures. Equation (1) contains not only v_n but v_r. But v_r is connected with v_n by the relation $F_r\, v_r = F_n\, v_n$, (F_n and F_r are sectional areas).

Hence, putting $\frac{F_n}{F_r}\, v_n$ for v_r, we have

$$\left.\begin{aligned} v_n &= \sqrt{\frac{1}{1-\left(\frac{F_n}{F_r}\right)^2}}\sqrt{2g\left[\frac{p_r}{\gamma}-\frac{p_n}{\gamma}\right]} \text{ for } A; \\ \text{and, for } B,\ v_n &= \sqrt{\frac{1}{1-\left(\frac{F_n}{F_r}\right)^2}}\sqrt{2g\,\frac{p_r}{\gamma}} \end{aligned}\right\} \quad (2)$$

It seems to me that a value of v_n thus computed—by equation (2)—is more strictly deserving of the name "*theoretical velocity*" than one based on the relation (used, I think, both by Mr. Freeman and Mr. Herschel):

$$v_n = \sqrt{2g\left[\frac{p_r}{\gamma}+\frac{v_r^{1\,2}}{2g}-\frac{p_n}{\gamma}\right]} \text{ for } A; \text{ and } v_n = \sqrt{2g\left[\frac{p_r}{\gamma}+\frac{v_r^{1\,2}}{2g}\right]} \text{ for } B \quad (3)$$

where v_r^1 is the actual or experimental value of the velocity through section r. For, if v_n^1 = the measured or actual velocity of the jet $= \frac{F_r\, v_r^1}{F_n}$, it follows from (3) that

$$\left.\begin{aligned} v_n &= \sqrt{2g\left[\frac{p_r}{\gamma}+\left(\frac{F_n}{F_r}\right)^2\frac{v_n^{1\,2}}{2g}-\frac{p_n}{\gamma}\right]} \text{ for } A; \\ \text{and } v_n &= \sqrt{2g\left[\frac{p_r}{\gamma}+\left(\frac{F_n}{F_r}\right)^2\frac{v_n^{1\,2}}{2g}\right]} \text{ for } B. \end{aligned}\right\} \quad (4)$$

In other words we are using the measured value of v_n to compute the "theoretical value!"

The point, therefore, is this, it seems to me: Theory is abundantly competent to find the "theoretical" v_n with no measurements save those of pressure and sectional areas. Does it not, therefore, savor somewhat of "begging the question" to employ in its computation the measured value v_n^1 or a quantity having a fixed relation to that measured value and obtained from it?

If it be then represented that the play-pipe takes the velocity as transmitted to it from the adjacent up-stream parts, it must be remembered that the velocity at any section of a pipe in which a steady flow is proceeding depends on all the features of the whole line of pipe from reservoir to, and including, the nozzle, so that a change in the resistance-character of a single part affects the velocities in all.

In the case of a nozzle or Venturi meter of such design as to cause

considerable loss of head between r and n, it seems clear that the value of the co-efficient $\frac{F_n\, v_n^1}{F_n\, v_n}$, or ratio of the actual to the theoretical discharge, with v_n computed from equation (2), would be quite different from that based on v_n as obtained from (3) or (4). In case, then, this co-efficient is to be taken as a measure of the efficiency of the apparatus used, it would seem that the former procedure is to be preferred (2).

As before remarked, this criticism may seem quite out of place as applying to Mr. Freeman's nozzles, most of which offered so little loss of head. It is made simply to bring up the question as to what should properly be termed the "theoretical velocity" of the jet, at n, in such a case.

Mr. Freeman.—Professor Church's point appears well taken, but, as he intimates, the error actually introduced is practically inappreciable. It will be noted, however, that in formula 1 of the appendix the expression is given in its true form.

Edmund B. Weston, M. Am. Soc. C. E.—I have been very much pleased and gratified by reading Mr. Freeman's instructive and valuable paper.

The value of n in the expression $v = n\,(r\,s)^{\frac{1}{2}}$, given in Table No. 7 of this paper, is, as deduced from my general formula* 116.4, which is almost exactly equal to the average of the results given in the same table that were obtained with hose designated by the letters *D* and *E*.

Then I find that the average of the co-efficients of discharge given in Table No. 1, which were determined from experiments made with smooth nozzles $\frac{3}{4}$, $\frac{7}{8}$, 1, $1\frac{1}{8}$, $1\frac{1}{4}$ and 1.55 inches in diameter, is 0.976, while the average of those deduced by myself from experiments made with smooth nozzles $\frac{7}{8}$, 1 and $1\frac{1}{8}$ inches in diameter,* is 0.971; also that the average of the co-efficients of discharge given in Table No. 3, which were determined from experiments made with square ring nozzles $1\frac{1}{8}$ and $1\frac{1}{4}$ inches in diameter, is 0.74, while the average of the results that I deduced from experiments made with square ring nozzles $\frac{7}{8}$, 1 and $1\frac{1}{8}$ inches in diameter*, is 0.721.

I have made a few comparisons, which are shown in the following table, of some discharges which I had at hand, that were calculated by my formula† for 1 inch smooth nozzles connected to $2\frac{1}{2}$ inch rubber hose of different lengths, with some of the discharges for 1 inch smooth nozzles connected to the best quality of rubber hose, given in Table A.

* Transactions American Society of Civil Engineers (Vol. XIII, November, 1884).

† In order to obtain the hydrant pressure, to correspond to my discharges, I added to the *h* given in my formula, 1.5 times the theoretical head due to the velocity of the water flowing in the $2\frac{1}{2}$ inch gauge coupling, 1.5 being a factor that I deduced from experiments made with a Providence Water Works hydrant, a number of years since.

Hydrant Pressure.†		Length of Hose.	Gallons Discharge per Minute.		
Pounds.	Feet.	Feet.	Weston.	Freeman.	Per Cent.
40.	92.4	50	172.5	174.0	99
98.	231.4	50	267.5	274.0	98
50.	115.5	100	184.0	186.0	99
100.	231.0	100	261.0	263.0	99
43.	99.3	200	158.0	161.0	98
94.	217.1	200	233.0	237.0	98
46.	106.3	400	143.0	147.0	97
92.	212.5	400	202.0	208.0	97
30.	69.3	1 000	88.0	93.0	95
90.	207.9	1 000	152.0	161.0	95

† See foot note previous page.

As will be seen, the average of the results in this table computed by my formula is only 2.5 per cent. less than the average of those of Mr. Freeman.

I consider the close agreement between the results of Mr. Freeman's investigations and my own in all of the preceding comparisons that I have mentioned remarkable, especially as I used hose that had been some time in service, and nozzles that were selected from general stock that were not made by the same manufacturers as those used by Mr. Freeman.

I quite agree with Mr. Freeman's idea, that nozzles on some occasions can be more advantageously used than weirs for accurately measuring small quantities of water. My formulas have been very frequently used since 1877 in the Water Department of the City Engineer's office in Providence for this purpose.

Mr. Freeman, while giving me credit for accuracy, infers that if my general formulas had been more conveniently arranged they could have been more extensively used. The principal object that I had in view when constructing these formulas was accuracy, as I was familiar with one or two simple formulas for the flow of water through rubber hose and nozzles that I consider the reverse. An examination of my formulas will show that they are arranged for obtaining direct results in cases where nozzles are attached to 2½-inch hose, or when the "open butts" consist either of 2½ or 2½-inch couplings, the pressure being obtained in the usual manner by connecting a pressure gauge to the hose near the hydrant or fire engine.

When I presented the results of my researches to this Society in 1884, I simply did so in order to give engineers, or others if they chose to make use of the formulas, an opportunity for obtaining results, that, in my opinion, could be relied upon. I should have been very glad, at the same time, to have been able to have furnished, in addition to formulas, practical tables, but as there were other things of much more

importance that required my attention I felt that I could not devote any more time to the subject.

R. HERING, M. Am. Soc. C. E.—I should like to call attention to some facts presented in the paper of Mr. John R. Freeman on Fire Streams. This shows a thoroughness in getting and arranging results for which the profession will feel greatly indebted, the merit of Mr. Freeman's work being enhanced by the fact that the experiments, conducted in a very careful manner, are an original contribution to the knowledge on fire streams, and one which I think will put the subject on a scientific basis.

While Mr. Freeman felt tempted to devise a formula from the results gained, he did not do so, preferring for the present to substitute tables and curves, partly because, as he well states, they are more convenient for use and less likely to be used far beyond the limits of the experiments from which they were derived.

While much could be said regarding the merits of the paper, I will confine myself to the subject of the effect of the variation of the degree of smoothness in small pipes, as Mr. Freeman's experiments give a valuable contribution to this subject. On page 358 he records the hydraulic elements for each experiment. By letters *A* to *L* he indicates the different kinds of hose used, and in Fig. 47 shows their degree of roughness by photographs of plaster casts.

I have taken the co-efficients of roughness as found by the Ganguillet & Kutter formula from their diagram, and found them to be as follows: (See table on next page.)

Any one comparing the co-efficients in the last column with the photographs of the respective hose will have a clear exhibition of the influence of roughness upon the velocity and consequently upon the pressure necessary to produce it, and also of the numerical value for the co-efficient corresponding to each degree of roughness illustrated.

I think it will require no further argument than a glance at the following Plate (Fig. 65), which is slightly re-arranged from that of Mr. Freeman, to convince any one that a formula for the flow of water in pipes should contain a variable co-efficient for the roughness of the perimeter, and at the same time to convince him of the usefulness of the Kutter formula in this respect, even granting its having a number of defects.

From the illustration it might appear that the fourth sample was rougher than the fifth, yet it gives a smaller co-efficient. This is only apparent, however, because the former has a surface of rubber while the latter has one of unlined linen with its unyielding cords and fibers to retard the water.

Bazin's experiments in a small trough lined with canvas give a higher co-efficient of resistance than in the above case, namely, .0134 to .0166

Sample or kind of hose.	Diameter of hose. Inches.	Square root of mean radius. r.	Sine of slope. s.	Mean velocity in hose. Feet per second.	Co-efficient in $v = c\sqrt{rs}$.	Kutter's co-efficient of roughness.
A	2.65	.235	.1863	12.50	123.3	.0073
	"	"	.2311	13.96	123.6	.0073
	"	"	.3404	17.00	124.0	.0073
	"	"	.4714	20.00	124.0	.0073
C	2.47	.227	.2464	13.40	119.1	.0075
	"	"	.3467	16.07	120.4	.0075
	"	"	.5269	20.00	121.5	.0074
D	2.49	.228	.2427	13.20	117.7	.0076
	"	"	.3351	15.81	120.0	.0075
	"	"	.4733	19.00	121.3	.0074
	"	"	.5708	21.00	122.1	.0074
E	2.68	.236	.0809	7.50	111.6	.0080
	"	"	.1440	10.00	111.6	.0080
	"	"	.2611	13.65	112.3	.0079
	"	"	.3931	17.00	114.8	.0078
I	2.69	.237	.2357	11.50	100.1	.0085
	"	"	.3120	13.55	101.7	.0084
	"	"	.4382	16.00	102.2	.0084
	"	"	.5165	18.00	105.8	.0083
M	2.12	.210	.3448	14.00	113.4	.0076
	"	"	.4897	17.00	114.8	.0075
	"	"	.7673	21.81	118.4	.0074
K	2.53	.230	.0261	3.50	94.3	.0088
	"	"	.0582	5.00	90.3	.0091
	"	"	.1384	7.50	87.8	.0093
	"	"	.2450	10.00	88.0	.0093
	"	"	.3425	12.00	89.3	.0092
	"	"	.5570	15.31	89.3	.0092
	"	"	.6748	17.00	90.1	.0091
	"	"	.8264	19.00	91.0	.0090
L	2.60	.233	.0414	3.50	73.9	.0102
	"	"	.0839	5.00	74.1	.0102
	"	"	.1846	7.50	74.9	.0102
	"	"	.3120	10.00	76.9	.0101
	"	"	.6286	14.50	78.5	.0100
	"	"	.8558	17.00	78.9	.0100
	"	"	1.1624	20.00	79.6	.0100

instead of .0100. This difference is probably due partly to the much higher velocity in the latter case, which will be appreciated by observing the variation of the co-efficient of roughness with the slope, and partly to the imperfections still remaining in the Kutter formula, as already mentioned.

Hamilton Smith's experiments in glass pipes give co-efficients of roughness of .0068 to .0073, *i. e.*, less than the smooth rubber-lined hose of Mr. Freeman's sample *C*, as might be expected. The numerous experiments with cast-iron pipes under higher velocity show co-efficients corresponding to Mr. Freeman's samples *I*, *K* and *L*.

I notice that these gaugings give a very satisfactory confirmation of a conclusion I reached some years ago, namely, that Kutter's co-efficient of roughness decreases as the slope or velocity increases, if the pipes

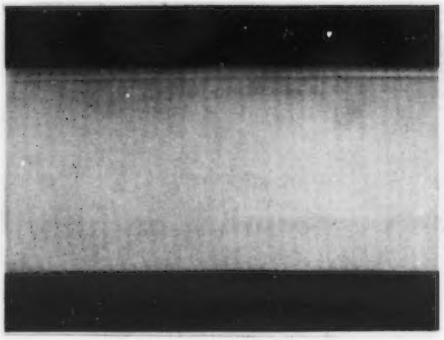
Fig. 65.

PHOTOGRAPHS FROM PLASTER CASTS OF INTERIOR OF FIRE HOSE.

(As per Fig. 47 in paper of Mr. John K. Freeman.)

Together with a description of the character of roughness of interior surface, and the numerical value of the Coefficient of roughness in the Ganguillet and Kutter formula for the mean velocity of water.

(Discussion by Rudolph Hering, M. Am. Soc. C. E.)



.0074 to .0075 Coeff. of roughness.

SAMPLE C. **WOVEN COTTON, RUBBER-LINED HOSE.**

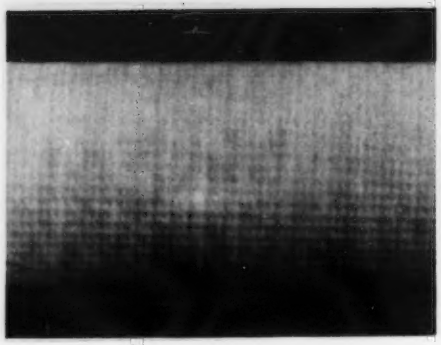
(Average depth of corrugations, $\frac{1}{1000}$ to $\frac{2}{1000}$ inch.)

14.1 lbs. pressure lost by friction per 100 feet.

Rubber lining slightly thicker than in sample K, and interstices between threads next lining well filled with rubber, so inner surface remained smooth under pressure.

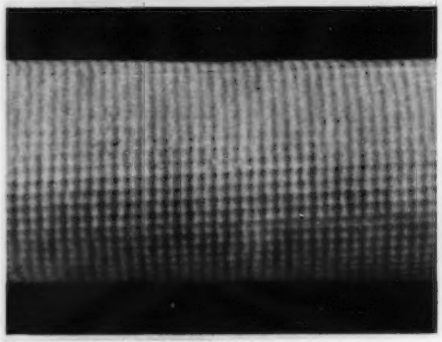
.0074 to .0076 Coeff. of roughness.

SAMPLE D had same kind of rubber lining, and gave loss of 14.2 lbs. per 100 feet.



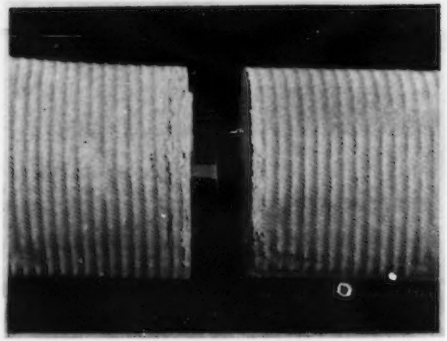
.0078 to .0080 Coeff. of roughness.

SAMPLE E. **KNIT COTTON, RUBBER-LINED HOSE.**
Interstices between threads next lining well filled.
16.0 lbs. pressure lost by friction per 100 feet in length (or 13 per cent more friction loss than in sample C).



.0083 to .0085 Coeff. of roughness.

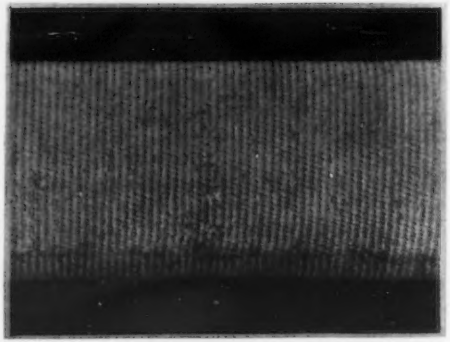
SAMPLE I. **KNIT COTTON, RUBBER-LINED HOSE.**
Interstices between threads next lining not well filled.
Average height of roundabout ridges, about $\frac{1}{100}$ inch.
Average height of ridges which run lengthwise, about $\frac{15}{1000}$ inch.
19.4 lbs. pressure lost by friction per 100 feet in length (or 37 per cent more friction loss than in sample C).



.0088 to .0093 Coeff. of roughness.

SAMPLE K. **WOVEN COTTON, RUBBER-LINED "MILL HOSE."**
(Average depth of corrugations, $\frac{15}{1000}$ to $\frac{2}{100}$ inch.)

25.5 lbs. pressure lost by friction per 100 feet in length of hose (or 80 per cent more loss than in sample D or C, shown below).
Rubber lining was rather thin, and crevices between threads next lining not being well filled, the water-pressure caused inner surface to conform to threads of fabric.



.0100 to .0102 Coeff. of roughness.

SAMPLE L. **UNLINED LINEN HOSE.**

33.2 lbs. pressure lost by friction per 100 feet in length (or 2½ times as much loss as in sample C, shown below).

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are fairly straight, regular and smooth. A revision of Kutter's formula should correct this feature, as the co-efficient of roughness ought to remain the same whatever the velocity is.

Mr. FREEMAN.—My thanks are due to Mr. Hering for his kind interest as shown by the care which he has taken to compare these experiments with that equation of most remarkable range of application, the Kutter formula.

Most earnestly do I concur in his conclusion that a satisfactory "formula for the flow of water in pipes should contain a variable co-efficient for the roughness of the perimeter;" but while the Kutter formula is useful in this respect as a formula for pipes, and inasmuch as it recognizes this principle is a long step in the right direction, yet I trust and believe that we shall before many years have a much simpler formula, designed for pipes alone, in which the same principle shall be incorporated.

As to the means by which such small roughnesses of surface are able to induce such powerful effects upon the friction loss, may we not consider that, instead of being due mainly to friction of the water upon the pipe, they are most likely due to the ability of these small projections to set the whole stream to its very center into a condition of turmoil and minute eddies, just as a single stone on the bottom of a smooth and deep canal is sometimes seen to produce a "boiling" at the upper surface?

Future experiment must determine the law governing the influence of projections of certain size, shape and arrangement upon the flow in pipes of various size, before this "satisfactory general formula" for flow in pipes can be derived. Other experimenters must give us for larger pipes of iron plastic representations of the exact degree of roughness corresponding to a given co-efficient of flow, or something analogous to the photographs which I have presented in Fig. 47, as pertaining to the more humble subject of fire hose, and then the means for properly designating the "variable co-efficient of roughness" in a general formula for flow in pipes will be at hand.

But yet that the friction loss does vary in relation to the velocity by a law somewhat different from the simple square is shown by the inclination of the plotted lines representing the values of n in Fig. 49, page 356. These variations are so slight, however, that it is clearly shown they may be disregarded in practical computations.

In reference to the demonstration that ring-nozzles have no special virtues, to which Mr. Kuichling refers with approval, I may mention that since, as he also suggests, so many men firmly believe in their merits, I took care to have some competent witnesses to this test, and so one day when Mr. James B. Francis, Mr. Clemens Herschel, Mr. E. B. Weston and fifteen or twenty other gentlemen skilled in these matters gave me the honor of their presence at a demonstration of the main

features of the experiments, we repeated the jet experiments as shown by Figs. 54 and 55, and although the two streams followed each other very closely, yet I am very sure that no one present would claim that either the square ring, under-cut ring or uniform acceleration-nozzles were in any degree better than the plain cone.